UNIVERSITY OF ALBERTA

**Integrated Information-based Construction Simulation System**

(IICSS)

BY

WAEL EL GHANDOUR ©

A thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree **of DOCTOR OF PHILOSOPHY**

In

Construction Engineering and Management

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

EDMONTON, ALBERTA

Spring 2007

Library and Archives Canada

Published Heritage Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et Archives Canada

Direction du Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

*Your file Votre référence*
*ISBN: 978-0-494-29668-4*
*Our file Notre référence*
*ISBN: 978-0-494-29668-4*

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

---

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

This thesis is dedicated with love, admiration, and respect to my parents, my wife, my sister, and my Children.

I'm but a product of your dreams and sacrifices

**ABSTRACT**

This study investigates the requirements needed to represent construction simulation components in an integrated and simple manner. With the proliferation of simulation languages and engines in construction, more areas of construction decision support are using simulation. Unfortunately, the specialized simulation models are often unable to exchange useful information directly, appearing like islands, separate and distinct from one another. The models are also complicated create, inconsistent, and their elements can seldom be combined.

State-of-the-art for simulation and information models in construction was reviewed and analysed, and the construction management information element was defined. The element serves as a common denominator between the varieties of traditional views of construction management data. Generic elements of project data were also developed to function as reusable simulation components. These elements can be assembled automatically to represent a specific area at any data abstract level for various construction management end-users.

This dissertation demonstrates the proposed solution to data unification in simulation models at both the conceptual level and in the implementation of simulation. The data representation scheme serves as a homogenizing framework for further research, and promotes the reuse and exchange of construction simulation knowledge in terms of these elements. The scheme allows researchers to work independently, while making it possible to produce parts of a modular whole. It addresses many of the most difficult issues in the integration of project information, and forms the basis of a practical and unified real-world simulation system. The approach proposed here uses several

techniques to develop a new Integrated Construction Simulation System (ICSS), which includes functions for image processing, information models, Ontology, High Level Architecture (HLA) distributed simulation system, and discovering similarities with natural laws. As a related study for enhancing the literature review for the research, surveys for broad applications of information technology in the construction research discipline were collected and analysed. As well a new automated data acquisition system has been developed to be used in the future as data input system for this integrated simulation approach. The automated data acquisition system has its limitations and may be applied only in certain circumstances and for specific construction processes.

## ACKNOWLEDGEMENTS

I would like to start by thanking all the industry members who have collaborated on the various research projects related to my thesis. This includes PCL. The financial and technical support of this company is greatly appreciated.

I would like to express my appreciation and thanks to Dr. Yasser Mohamed for his sincere support and technical views that gave ease to my research work and facilitated my thesis. Also I would like to express my appreciation to the members of my dissertation committee, Professors Makarand Hastak, Roger Toogood, J.C. Cunha, Simaan AbouRizk, and Yasser Mohamed.

The completion of a large undertaking is seldom the accomplishment of an individual alone. My thanks go to numerous friends, colleagues and coworkers who generously contributed ideas, discussion time and support. Finally, my deepest appreciation goes to my parents and my sister for their love and support, and to my dearest friend, partner and wife, Sherin ElTahan, and my kids. We did it.

My most sincere thanks and gratitude to my supervisor, friend, and mentor, Dr. Simaan AbouRizk, who took me under his wing, treated me as a brother, and showed me endless patience and encouragement through the whole dissertation process. His advice and confidence were essential for the completion of this thesis. Certainly, this dissertation could not have been started, let alone finished, without his input, guidance, trust, and endless scientific and moral wisdom.

Funding for my research was provided in part by the University of Alberta, the Government of Alberta, the Natural Science and Engineering Research Council of Canada, and the National Research Council.

## Table of Contents

**CHAPTER 1.... INTRODUCTION ..... 1**

1.1. INTRODUCTION ..... 1

1.2. BACKGROUND ..... 2

1.2.1. Limitations of Existing Systems ..... 2

1.2.2. Needs for Integrated Construction Simulation System ..... 3

1.2.3. Information Technology Applications in Construction ..... 4

1.2.4. Data Acquisition ..... 4

1.3. RESEARCH OBJECTIVES AND CONTRIBUTIONS ..... 5

1.3.1. Research Objectives ..... 5

1.3.2. Anticipated Research Contributions ..... 5

1.4. RESEARCH METHODOLOGY ..... 8

**CHAPTER 2.... INFORMATION MODELING AND SIMULATION APPLICATION IN CONSTRUCTION – COMPARATIVE STUDY ..... 10**

2.1. ABSTRACT ..... 10

2.2. INTRODUCTION ..... 10

2.3. REVIEW OF CONSTRUCTION SIMULATION MODELS ..... 15

2.4. ANALYSIS OF CONSTRUCTION SIMULATION REVIEW ..... 22

2.5. REVIEW OF CONSTRUCTION INFORMATION MODELS ..... 27

2.6. ANALYSIS OF INFORMATION MODELS APPLICATIONS REVIEW ..... 31

2.7. COMPARATIVE STUDY ..... 36

2.8. FUTURE RESEARCH NEEDS ..... 42

2.9. CONCLUSIONS ..... 49

2.10. REFERENCES ..... 50

**CHAPTER 3.... INTEGRATED INFORMATION ARCHITECTURE FOR SIMULATION SYSTEM IN CONSTRUCTION MANAGEMENT ..... 55**

3.1. ABSTRACT ..... 55

3.2. INTRODUCTION ..... 55

3.3. APPROACH ..... 59

3.4. INTEGRATED SIMULATION - INFORMATION ARCHITECTURE ..... 59

3.5. CONCLUSION ..... 67

3.6. REFERENCES ..... 67

APPENDIX 1 – GENERAL AND COMPETENCY QUESTIONS TO DEFINE SCOPE AND DOMAIN OF ONTOLOGY ..... 72

APPENDIX 2 – CONSTRUCTION INFORMATION ELEMENTS DESCRIPTION AT ABSTRACT LEVEL 4 ..... 78

**CHAPTER 4.... INTEGRATED DISTRIBUTED SIMULATION SYSTEM FOR CONSTRUCTION MANAGEMENT ..... 99**

4.1. ABSTRACT ..... 99

4.2. INTRODUCTION ..... 100

4.3. HIGH LEVEL ARCHITECTURE BACKGROUND ..... 102

4.4. DISTRIBUTED INFORMATION-BASED SIMULATION SYSTEM IMPLEMENTATION ..... 104

4.5. CASE STUDY ..... 116

4.6. CONCLUSIONS ..... 127

4.7. REFERENCES ..... 127

APPENDIX 1 – DESCRIPTION OF FEDERATES ..... 129

APPENDIX 2 – LPs OF IICSS4 FEDERATES ..... 131

**CHAPTER 5.... IICSS AND NATURAL LAWS – NEW APPROACH ..... 157**

5.1. ABSTRACT ..... 157

5.2. INTRODUCTION ..... 157

5.3. REVIEW OF CHEMISTRY ..... 159

5.3.1. ORGANIZATION OF MATTER ..... 159

5.3.2. ATOMIC STRUCTURE THEORIES ..... 161

5.3.3. ELECTRONIC CONFIGURATION TABLE ..... 161

5.3.4. TYPES OF CHEMICAL ELEMENTS ..... 163

5.3.5. PERIODIC TABLE ..... 163

5.3.6. CHEMICAL BONDS & REACTIONS ..... 164

5.3.7. SUMMARY ..... 165

5.4. COMPARISON OF CONSTRUCTION MANAGEMENT SIMULATION INFORMATION FLOW & CHEMICAL SYSTEM ..... 166

5.4.1. INTRODUCTION ..... 166

5.4.2. OPPORTUNITIES OF APPLYING THE CHEMICAL ENVIRONMENT TO THE CONSTRUCTION MANAGEMENT INFORMATION SIMULATION ENVIRONMENT ..... 167

5.5. PROTOTYPE MODEL ..... 181

5.6. POTENTIAL FUTURE WORK ..... 186

5.7. SUMMARY ..... 187

5.8. REFERENCES ..... 187

**CHAPTER 6.... APPENDIX - RELATED RESEARCH WORK ..... 189**

6.1. ABSTRACT ..... 189

6.2. SURVEY OF INFORMATION TECHNOLOGY APPLICATIONS IN CONSTRUCTION ..... 190

6.2.1. ABSTRACT ..... 190

6.2.2. INTRODUCTION ..... 190

6.2.3. RESEARCH FRAMEWORK ..... 192

6.2.4. INFORMATION TECHNOLOGY IN CONSTRUCTION (ITC) ..... 193

6.2.5. ANALYSIS OF ITC APPLICATIONS ..... 196

6.2.6. CONCLUSIONS ..... 212

6.2.7. REFERENCES ..... 213

6.3. AUTOMATED DATA ACQUISITION SYSTEM ..... 217

6.3.1. ABSTRACT ..... 217

6.3.2. INTRODUCTION ..... 218

6.3.3. IMAGE PROCESSING APPLICATIONS BACKGROUND ..... 221

6.3.4. FRAMEWORK ..... 231

6.3.5. MODELS DEVELOPED ..... 235

6.3.6. VALIDATION ..... 246

6.3.7. RECOMMENDATIONS ..... 249

6.3.8. SUMMARY ..... 250

6.3.9. ACKNOWLEDGMENT ..... 251

6.3.10. REFERENCES ..... 251

APPENDIX 1 – CODE OF REAL TIME DATA ACQUISITION SYSTEM..... 255

**CHAPTER 7.... FINAL DISCUSSION..... 278**

7.1. RESEARCH SUMMARY ..... 278

7.2. SUMMARY OF RESEARCH CONTRIBUTIONS ..... 279

7.3. RECOMMENDATIONS FOR FUTURE DEVELOPMENT ..... 281

## List of Tables

Table 2-1 : Comparison between Functions of various Construction Simulation Engines and/or Languages according to Objects to be modeled.....26

Table 2-2 :Comparison between various Construction Information Models Functions35

Table 2-3 : Matrix of Objectives vs. Tools for Integrated Information-based Simulation System .....48

Table 3-1 : General Questions .....72

Table 3-2 : Competency Questions at Level 4.....74

Table 3-3 : Competency Questions at Level 3.....75

Table 3-4 : Competency Questions at Level 2.....76

Table 3-5 : Competency Questions at Level 1.....77

Table 4-1 : Matrix of IICSS Elements Mapping to HLA Objects .....107

Table 4-2 :Comparison of Developing Integrated Simulation Model using Traditional Method and New Approach .....126

Table 5-1 : Chemical classes of Construction Management Information Simulation Elements.....171

Table 5-2 : Chemical Interaction Capabilities of Construction Management Simulation Elements.....172

Table 5-3 : Types of Chemical Relationships between Construction Management Simulation Elements .....175

Table 5-4 : Types of Valence information between Construction Management Information Simulation Elements .....176

Table 5-5 : Comparison of Developing the Model using Traditional and New Technique ..... 183

Table 6-1 : Matrix for the 43 areas of application for the selected 9 ITC tools..... 197

Table 6-2 : Matrix for the 9 ITC tools applications published in the 12 studied scientific journals ..... 198

Table 6-3 : Sequence of ITC tools applications in ITC areas ..... 205

Table 6-4 : Percentage of published papers based on each ITC ..... 207

Table 6-5 : Degree of generic-applicability for each construction area..... 210

Table 6-6 : Matrix of integration-ability of each pair ..... 212

Table 6-7 : Comparison of collected data using new system and human observations 247

## List of Figures

Figure 1.1 : Research Objectives, Applied Tools, and Anticipated Contributions.....7

Figure 1.2 : Research Methodology.....9

Figure 2.1 :Complicated Relationships among Construction Information Environment13

Figure 2.2 : Illustration of Construction Information Environment .....13

Figure 2.3 : History of Construction Simulation Models .....25

Figure 2.4 :History of Construction Information Modeling .....34

Figure 2.5 :Construction Information Models View Model using EXPRESS-G .....38

Figure 2.6 : Construction Simulation Models View Model using EXPRESS-G.....41

Figure 2.7 : Fragmented information flow between simulation and construction management areas .....42

Figure 2.8 : Proposed abstraction levels hierarchy for construction management. .....45

Figure 3.1 : Ontology Approach .....58

Figure 3.2 : Information Abstract Levels proposed by Sanvido et al (1995) .....60

Figure 3.3 : Information Abstract levels proposed by Halpin and Woodhead (1986).60

Figure 3.4 : Information Abstract Levels and Examples of End-Users.....61

Figure 3.5 : Simulation-Information Elements Structure .....62

Figure 3.6 : Simulation-Information Elements Map at Abstract Level 1 (Organization Level) .....63

Figure 3.7 : Simulation- Information Elements Map at Abstract Level 2 (Project Level) .....64

Figure 3.8 : Simulation- Information Elements Map at Abstract Level 3 (Product Level) .....65

Figure 3.9 : Simulation-Information Elements Map at Abstract Level 4 (Task Level)66

Figure 4.1 : Flow Chart of Prototype Development ..... 104

Figure 4.2 : Structure of IICSS in HLA Environment ..... 106

Figure 4.3 : IICSS FOM ..... 114

Figure 4.4 : User-interface of Schedule Control Federate at Abstract Level 4 ..... 115

Figure 4.5 :Prototype Model ..... 124

Figure 4.6 : Prototype Model using Simphony ..... 125

Figure 5.1 : Organization of Matter (Zumdahl 2000) ..... 160

Figure 5.2 : Example Compound ..... 160

Figure 5.3 : Order of orbital (energy level) around polyelectronic atom (Zumdahl 2000) ..... 162

Figure 5.4 : Electronic Configuration of Boron (B) & Helium (He) elements ..... 163

Figure 5.5 : Periodic Table ..... 164

Figure 5.6 : Molecules and Chemical Reactions (Zumdahl 2000) ..... 165

Figure 5.7 : Information Elements Maps Key using Chemical Similarity ..... 170

Figure 5.8 : Description of information interaction equations of simulation elements173

Figure 5.9 : Prototype Excel model ..... 184

Figure 5.10 : Prototype model application in Simphony ..... 185

Figure 6.1 : Number of published papers for each ITC tool in 1994 ..... 199

Figure 6.2 : Percentage of total published papers for each ITC tool during the period 1992-2001 ..... 200

Figure 6.3 : Number of published papers for each construction area in year 2000 ... 203

Figure 6.4 ; Number of published papers for each construction area using GIS ..... 204

Figure 6.5 : Percentage of the total number of published papers related to the construction phases during the period of the study (1992- 2001).....206
Figure 6.6 : Percentage of generic applications for each ITC tool in the published papers .....208
Figure 6.7 : Percentage of generic applications of ITC tools in the published papers for each construction area.....209
Figure 6.8: Percentage of integration-ability .....211
Figure 6.9 : Pixel neighborhoods (Sonka et al. 1999).....225
Figure 6.10 :RGB Image.....228
Figure 6.11 : Histogram of One band and Mesh diagram for Color-Intensity Image229
Figure 6.12 : Creating a Temporary Matrix for Sliding Neighborhood .....230
Figure 6.13 : Image size and coordinates.....232
Figure 6.14 : Image Capturing System .....232
Figure 6.15 : Images of recognized truck .....234
Figure 6.16 : General description of proposed method.....237
Figure 6.17 : Manual selection of required object.....238
Figure 6.18 : Selected part of required object.....239
Figure 6.19 : A sample of color intensity for the three main bands of selected pixel within a selected object. .....240
Figure 6.20 : Original first image in the working day .....241
Figure 6.21 : Selected part of the image as a new image.....242
Figure 6.22 : Algorithm of X, Y coordinates.....244
Figure 6.23 : Median method to define accurate coordinates of objects .....244

Figure 6.24 : Initial data collected using image processing system.....245

Figure 6.25 : Calculated times using developed macro .....246

Figure 6.26 : Suggested position of the webcam in the construction site.....250

# CHAPTER 1. INTRODUCTION

## 1.1. INTRODUCTION

The Integrated Information-based Construction management Simulation System (ICSS) is an advanced technology that meets the needs of all knowledge areas and processes in construction management. The objectives of IICSS are to improve efficiency, integrate information, simplify simulation model building, ease the interface with end-users, and produce various outputs using the same simulation systems for construction management. The dynamic nature of resource interaction, the amount of information flow, and uncertainties in task durations can be efficiently analysed using simulation systems. With a better understanding of the construction project, its processes, and its management output before actual work starts, end-users of these simulations can optimize the allocation of their resources, modify their plan and schedule, and/or update their cashflow to increase productivity, eliminate rework, enhance performance, increase progress reliability, reduce costs, improve quality, and increase the opportunity of finishing the project ahead of the schedule.

Image processing, information models, Ontology, distributed simulation system High-Level Architecture (HLA), and chemical theories and principles are selected application tools used in this research to develop a new IICSS. Image processing is used in developing a new automated data acquisition system that can collect the data and send it immediately to the simulation model. This system can be applied to remote and

hazardous construction sites for excavation and similar processes. Information models are used to identify information that is produced and utilized by the information-based simulation elements and their interactions. Ontology is utilized to systematically define standard definitions and structures for simulation elements. The HLA concept is used to build a distributed simulation system and reflects various information at abstract levels for end-users. Chemical principles and theories are used to increase the intelligence of simulation elements and its interoperability for construction management.

This research will contribute to the defining of a framework for representing and integrating the key decisions and intent of the various participants in the construction management process, and to look for new methods that take advantage of the simulation's full capabilities.

## 1.2. BACKGROUND

### 1.2.1. Limitations of Existing Systems

Although construction information models, and simulation models and languages have been developed for many years in academic research, they have not been adopted and accepted in the construction industry to any significant degree, least of all simulation models and languages. While information models have some industry applications as in the case of Industry Foundation Classes (IFC), simulation models are still lacking.

The major limitations of simulation models application in industry use can be summarized as:

1) The large and complicated amount of information that must be included in the simulation models.

2) Their inability to automatically control transfer between their elements during the simulation run.
3) The unacceptable ontology and structure of their elements for construction industry end-users.
4) The continuous increase in construction information that affects simulation models.
5) Its inability to produce, at the same time, formatted data required by industry such as cashflow, performance factors, estimate at completion, and forecasted start and finish dates.

### 1.2.2. Needs for Integrated Construction Simulation System

A large amount of information is created and used in simulation models to express the life cycle of a construction project and its management processes. This information is used by many end-users at different times and with various perspectives. Many information models and languages for construction have been developed; therefore in order to take advantage of the huge amount of information in the construction industry, an information based simulation system must be designed to collect and integrate the data between construction management processes. Simulation elements should be built in a systematic and well defined way to secure significant automated interaction between these elements during the simulation run. It can also increase the acceptability of simulation models within the construction industry and provide a means to achieve an effective and coordinated exchange of information with the inter-disciplinary processes in construction management. During a simulation run, the information contributed by each

process is stored consistently, and made accessible to other construction management processes within the simulation environments.

### 1.2.3. Information Technology Applications in Construction

Many research papers have been published in the construction domain using various tools of information technology (IT) such as: 3D rendering, simulation, fuzzy set theory, database systems, data modeling, expert systems, neural networks, geographic information systems, and virtual reality. Application areas in construction are not well covered by these tools. Furthermore, future trends in IT applications in construction have not been defined until now. Some surveys have been developed to analyse IT applications in the construction industry, but no one has organized a similar one for IT applications in construction research. Increasing knowledge in this area could enhance the opportunity for researchers to anticipate new potential research areas of IT applications in construction.

### 1.2.4. Data Acquisition

The present data acquisition system used for work measurement in construction sites is based mainly on human involvement. The elimination of human factors in this system will increase its reliability and accuracy. Analysis tools used to analyse these collected data are post-data acquisition tools. Developing a new data acquisition system that could collect and send data automatically to the analysis tools could enhance the credibility and acceptability of these tools, including simulation systems, among construction industry end-users. Image processing is a cost-effective and accurate tool that can be applied to

develop this system. Image processing has some limited applications in construction research that could be extended to data acquisition system.

## 1.3. RESEARCH OBJECTIVES AND CONTRIBUTIONS

### 1.3.1. Research Objectives

This research has the following objectives:

1) To analyse the research efforts done in both information and simulation model.
2) To integrate the simulation system and the information from construction management process.
3) To integrate the HLA with simulation and information-based simulation models.
4) To introduce chemical theories and principles as a new research tool that can be used in developing simulation systems.
5) To explore and analyse information technology tools that have been applied in construction research, and to predict their potential trends. As well to demonstrate the application of image processing in construction data acquisition.

### 1.3.2. Anticipated Research Contributions

This research has the following anticipated contributions:

1) The integration of several construction management processes (cost control, time control, cost estimate, documentation management, and others) under the same simulation system umbrella.

2) Introducing automated elements in simulation systems. These elements are able to verify the type of elements that they can interact with Also they are able to define type of data that should be transferred between them during the simulation run. They can also identify the method with which to interact with other elements in the system.
3) Building a new standard anatomy for construction management information elements that, in the future can have new elements added easily to it with the same criteria. These new elements can be easily integrated with existing elements.
4) Initiation for developing a standard library for construction management simulation systems
5) Distribution of simulation data and viewability of various construction management simulation data at all levels of abstraction.
6) A basis for an automated approach to create new elements during the simulation run.
7) Acquiring a simple, high level and generic information model for construction management.
8) Discovering potential research areas for application of information technology in construction.
9) Developing a new approach for automated data acquisition system using image processing in construction sites.

The main contribution of the research is to simplify the simulation interface with the end-users. Figure 1.1 describes objectives, tools, and main contributions for research conducted in this thesis.

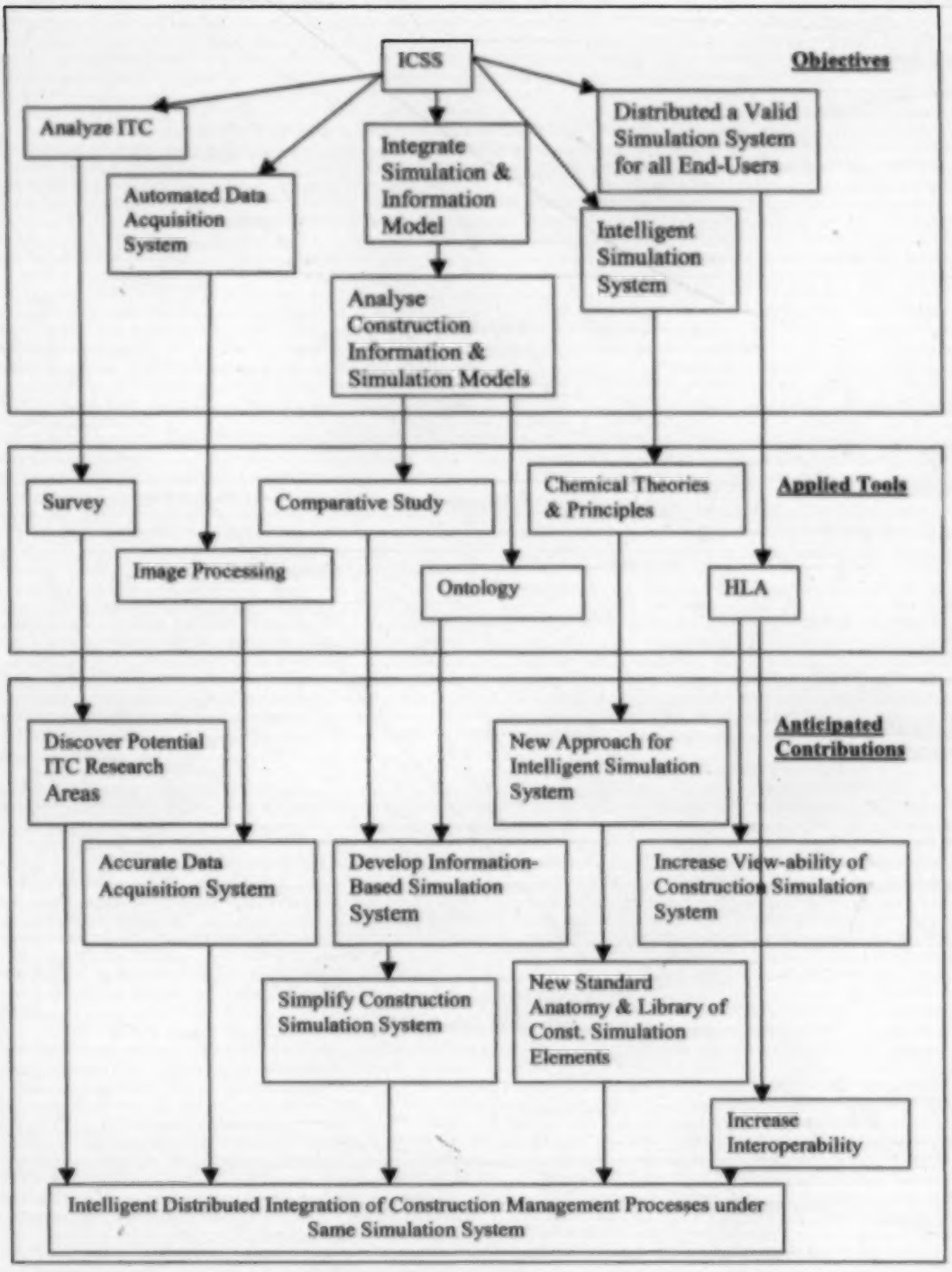



**Figure 1.1 : Research Objectives, Applied Tools, and Anticipated Contributions**

## 1.4. RESEARCH METHODOLOGY

The research follows the steps described in Figure 1.2 to achieve its goals and objectives. A prototype system will be designed and developed to accomplish these objectives under a revised *Simphony* environment that applies HLA standards. This system is developed by the research team at the Hole School of Construction Engineering at the University of Alberta. One of the main advantages of this research approach is that it naturally matches the realistic representation of real world objects.

The main tasks in the proposed methodology will be as follows:

1) Survey and analyse current applications of information technology in construction (ITC) research.
2) Survey and compare current simulation models, and information models and languages in construction research.
3) Define construction information levels of abstract to suit all end-users.
4) Review Ontology and its application in construction research.
5) Define construction information elements.
6) Design a construction information model for simulation and management application
7) Review chemistry theories and principles
8) Build a new anatomy for information elements.
9) Build new pattern for information transfer and relationships between simulation elements, including new Ontology.
10) Create a conceptual design for simulation using HLA.

11) Design simulation algorithm for each federate in HLA, where the federate is a collection of interacting simulations in HLA

12) Develop a prototype simulation system.

13) Apply and validate case study.

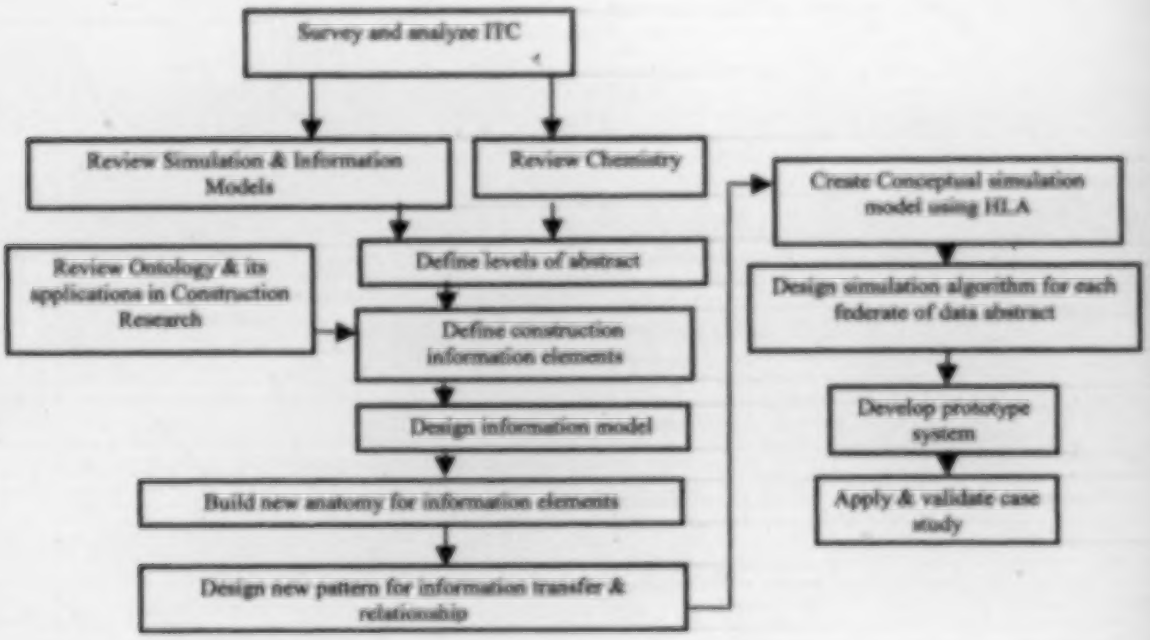

Survey and analyze ITC
Review Simulation & Information Models
Review Chemistry
Review Ontology & its applications in Construction Research
Define levels of abstract
Define construction information elements
Design information model
Build new anatomy for information elements
Design new pattern for information transfer & relationship
Create Conceptual simulation model using HLA
Design simulation algorithm for each federate of data abstract
Develop prototype system
Apply & validate case study

**Figure 1.2 : Research Methodology**

# CHAPTER 2. INFORMATION MODELING AND SIMULATION APPLICATION IN CONSTRUCTION – COMPARATIVE STUDY

## 2.1. ABSTRACT

This paper is concerned with comparing information and simulation modeling in construction Research and Development (R&D). It examines the fundamental concepts of simulation and information modeling by discussing the various models that have been designed, as well as approaches used to develop them. A detailed survey and analysis of recent R&D projects that have sought to develop simulation and information modeling is also presented. The overall objective is the analysis of the relation between information modeling and simulation modeling in construction, and the possibilities of their integration. The paper concludes with an identification of gaps in current R&D and recommendations for strategic advice on the future development of Integrated Information-based Construction Simulation System (IICSS).

## 2.2. INTRODUCTION

There is a noticeable breakdown in the transfer of construction information between simulation tools and other construction applications software. This breakdown can lead to poor decision-making, duplication of effort, an inability to exchange information directly, the prevention of understanding between project coordinators, other possible errors, and changes to the original objectives and plan of the simulation model. This breakdown is one of the main reasons for the limitation of simulation application in

construction. Since the original implementation of computers within construction discipline, there has been a focus on integrating all software applications within and around the CAD system. This vision still looks to the CAD system as the center of this integration, though at the same time some efforts to integrate construction simulation engines with other applications have been made.

Previous studies have focused on modeling either the information or the simulation, without adequate consideration of the significance each has in relation to the other. The disintegration and asynchronous of construction information flow between various decision support tools such as simulation and construction software are responsible for large amounts of wasted time and money, and misleading decisions. These issues are also responsible for hindering the application of simulation application in the construction industry. Information models are very important for securing the exchange of project information between various computer systems and decision support tools. At the same time, simulation is one of the powerful decision tools that have been recently applied to the construction discipline. Despite having been researched for approximately three decades, simulation in construction remains impractical. One of the main reasons for this impracticality, besides the others of its difficulty and inherent limitations, is its inability to integrate various construction management processes under the same simulation environment as well as its fragmentation and disassociation from other construction software (Shi and AbouRizk 1997). The developed simulation models gave a little attention to information management. One of the main reasons for their isolation is that both models are not modeling the construction environment at the same level of detail. Traditionally, construction information modeling has focused on the integration of

process and product level at the design and planning. In addition, simulation models developed to now have not been adapted to the standardization efforts that have been made in the construction industry, in terms of both data classification and data sharing. Furthermore, the detailed processes at the lowest abstract level, including its sub-processes and tasks which are necessary to generate the product, are largely ignored. The construction information environment is characterized by complicated relations and interdependences among its various elements as shown in Figures 2.1 and 2.2. Figure 2.1 describes the complexity of information flow between some construction information elements. It shows how information is transferred in both directions between all the elements. Any actor is requiring resource to execute any task to produce the required product under one of the construction process, which is documented in a document. Figure 2.2 illustrates an excavation process as an example describing this environment. The elements are described as the following:

**Task**: excavate – load – dump

**Actor**: labor

**Process**: excavation

**Product**: pit

**Document**: schedule

**Resources**: excavator - loader - truck

**Figure 2.1 :Complicated Relationships among Construction Information Environment**

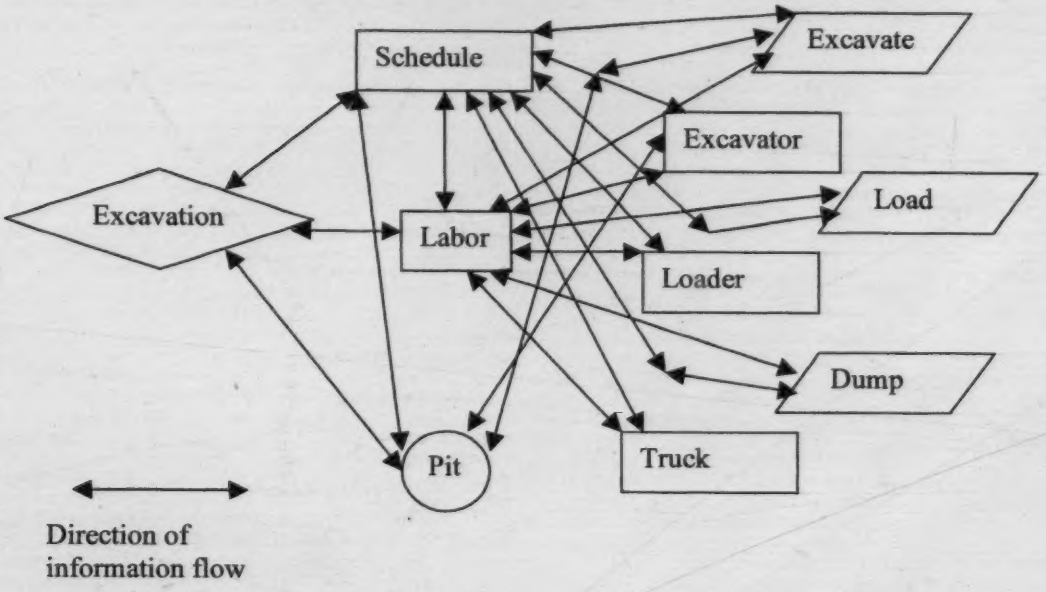



**Figure 2.2 : Illustration of Construction Information Environment**

Although of these noticeable complications, the relations can be analysed as simple reactions between the same elements to produce other elements, such as actors,

management objects, documents, and others. Chua and Li (2001) tried to describe these relations in construction by describing relations among resources and among processes only. This description lacked vital information elements. It did not describe interactions between different types of construction elements, but describing only the interactions among the same type (resources or processes).

O'Brian (1996) mentioned that accomplishment of system integration is itself dependent upon the success of data integration. Amor and Anumba (1999) surveyed and analysed the construction project integrated database. They described the approaches used for developing integrated project database (IPD) as following: project model as reference model, centralized project database, neutral format project database, and proprietary approaches. They surveyed seven main IPD in UK projects including: COMBINE, ICON, OSCON, SPACE, COMMIT, ToCEE, and WISPER. These projects were analysed based on six criteria. Among these projects, not one focused on lower levels of activities (sub-activities and tasks) in construction. Some of them included only coverage for various construction management processes such as scheduling, planning, and estimating management areas. Simulation developing characteristics were not utilized in these models. An integrated simulation information model not only encourages those involved in construction to use and add to the design information, but also provides richer information representation, better efficiency and data consistency, and the flexibility to support life-cycle information management.

Our goal is to analyse the current developed construction information modeling to focus on simulation as one of the main construction decision-support tools by analyzing state-of-the-art models, and to compare both tools to define criteria required for their

integration. The next section addresses the types of construction simulation engines according to the simulation strategies, objects to be modeled and underlying simulation algorithms. The major contributions to construction simulation literature are highlighted and construction simulation needs are also addressed. A brief review of definitions and main engines developed for each type is presented and the main differences between these engines are declared.

## 2.3. REVIEW OF CONSTRUCTION SIMULATION MODELS

Construction simulation is defined as the process of designing a mathematical logic model of a real construction project and experimenting with the model on a computer. Simulation as a tool for the construction industry is a very practical and promising one, specifically in terms of the engineering and management aspects. It is a cost-effective way for comparing alternatives and analyzing decisions in order to arrive at the most suitable conclusion, whenever mathematical modeling approach is not available. It gives the user the ability to change the logic of the construction process, by adding, deleting, or updating any element. In this way, suitable solutions of the construction problem can be found without implementing these changes in reality. The uniqueness, complexity, and sudden changes of construction processes have made this tool into one of the most suitable decision-support tools in construction especially in the field-level decisions. Shannon (1975) defines simulation as "The process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system". The advantage of

construction simulation modeling is its ability to conceptually carry out a project, construction method, change order, check the constructability, or plan the resource allocation time and time again for a variety of scenarios until the most effective solution can be found. It allows the construction engineer to modify the model at any time during the life cycle of the construction process and with no limit on the number of modifications that can be made.

One of the first efforts in this area is CYCLONE (Halpin 1977). It is one of the best discrete-event simulation languages made for the construction discipline. It was developed based on a process-oriented network simulation approach. It built a foundation for other simulation systems, such as: RESQUE (Chang 1986), Um-CYCLONE (Ioannou 1989), COOPS (Liu and Ioannou 1992), and DISCO (Huang et al. 1994), and others. Different approaches were developed later, such as: CIPROS (Tommelein et al. 1994). This language has been developed as an object oriented and interactive system that integrates project and process-level planning. AbouRizk , and Hajjar (1998) described a special purpose simulation and differentiate between it and libraries. McCabe and AbouRizk (2001) described, in details. many of these approaches and languages.

The main types of simulation engines, modeling tools and/or languages developed for construction applications can be classified according to the objects to be modeled, the underlying simulation algorithms, and the scope of coverage as follows:

1) <u>According to the objects to be modeled:</u>
    a. Process-oriented simulation
    b. Resource-oriented simulation
    c. Activity-oriented simulation

d. Product-oriented simulation

e. Function-oriented simulation

2) <u>According to underlying simulation algorithms :</u>

a. Discrete-event simulation algorithm (dynamic process interaction)

b. Static simulation algorithm

c. Continuous or time-dependent algorithm

3) <u>According to the scope of coverage:</u>

a. General-purpose simulation

b. Special-purpose simulation

In the following section, definitions and the main developed languages and engines for each type of construction simulation will be discussed.

**1) <u>According to the objects to be modeled:</u>**

To this point, five main simulation types have been defined according to the main objects that are modeled in the simulation engine. Although there can be more than one object that are modeled together in some of these engines, there is only one object that the engine or model has been designed for.

A- <u>Process-oriented simulation</u>

**Definition:**

It is the presentation of a construction operation as a collection of processes that interact with each other through certain strategies. The interdependence and inter-linkage of the processes represent the construction operation logic and utilization of common resources.

**Main developed engines, modeling tools and/or languages:**

1) CYCLONE (Halpin 1977)
2) RESQUE (Chang 1986)
3) UM-CYCLONE (Ioannou 1989)
4) COOPS (Liu and Ioannou 1992)
5) DISCO (Huang et al. 1994)
6) HSM (Sawhney and AbouRizk 1995)
7) CIPROS (Odeh 1992)
8) STEPS (McCahill and Bernold 1993)
9) STROBOSCOPE (Martinez 1996)

B- Resource-oriented simulation

**Definition**:

This is the type of construction operation modeling which pertains to independent resources and focuses mainly on other interactions. This type of simulation takes construction resources as modelling objects (David and Li 2002). This modelling requires developing a resource pool for the entire project.

**Main developed engines, modeling tools and/or languages:**

1) LBS (Oloufa et al. 1998)
2) RISim (David and Li 2002)
3) RBS (Shi and AbouRizk 1997)

C- Activity-oriented simulation

**Definition**:

This is the type of construction operation modeling which deals directly with independent activities and their interactions. The difference between activity and process can be identified according to definitions from Halpin and Riggs (1992). Construction process is defined in terms of collections of activities, and activities are readily identifiable components of the construction process, which consumes both time and resources to be constructed.

**Main developed engines, modeling tools and/or languages:**

1) AUTOSIM (Paul and Chew 1987)
2) Activity Cycle Diagram and the Three Phase Method (Paul 1993)
3) Graphical Simulation Model (Au and Paul 1994)
4) ABC (Shi 2000)
5) Iconic Animation for ABC (Zhang and Shi 2002)

D- Product-oriented simulation

**Definition**:

This type of simulation focuses on the product or the final output of the construction project, any of its processes or activities, and tracking its life cycle during the phases of the project.

**Main developed engines, modeling tools and/or languages:**

1) CAD-ISE ( Xu J.and AbouRizk S. 2001)

E- Function-oriented simulation

**Definition**:

This simulation type describes the behavior of the construction element in a manner beyond what current simulation techniques allow. It lists the functions of this element and provides those involved in construction the means for representing "why" an element exists in a system.

**Main developed engines, modeling tools and/or languages:**

1) Systematic Simulation Framework (Mohamed Y. and AbouRizk 2002)

**2) According to underlying simulation algorithms:**

A- Discrete-event simulation (Dynamic process interaction) algorithm

**Definition**:

This algorithm utilizes next-event processing of activities components and availability of resources. This type of algorithm is dynamic in nature.

**Main developed engines, modeling tools and/or languages**:

1) CYCLONE (Halpin 1977)
2) The AP2_Earth simulation engine (AbouRizk and Hajjar 1997)
3) *Simphony* (AbouRizk and Hajjar 2001)

B- Static simulation algorithm

**Definition**:

This algorithm is driven by a prescribed processing flow that is not dependent on time, interaction, or resources.

**Main developed engines, modeling tools and/or languages:**

1) VEHISM program (Caterpillar 1987)
2) The CRUISER simulation engine (AbouRizk and Hajjar 1997)
3) *Simphony* (AbouRizk S. and Hajjar D. 2001)

C- Continuous or time-dependent algorithm

**Definition**:

This algorithm is often represented with a system of equations or mathematical models and then solved for steady state performance using differentiation, integration, or approximation.

**Main developed engines, modeling tools and/or languages:**

1) The CSD simulation engine (AbouRizk and Hajjar 1997)
2) *Simphony* (AbouRizk and Hajjar 2001)

**3) According to scope of coverage:**

A. General-purpose simulation

**Definition:**

This is the model developed in a simulation environment using a general simulation programming language, which has elements that can be used as an abstract for any real element in our life and in some or all of the disciplines.

**Main developed engines, modeling tools and/or languages:**

1) CYCLONE (Halpin 1977)
2) RESQUES (Chang 1986)

3) Visual SLAM (Pritsker and O'Reilly 1999)

4) COOPS (Liu 1991)

5) CIPROS (Odeh 1992)

6) STROPOSCOPE (Martinez 1996)

7) Common Template in *Simphony* (AbouRizk and Hajjar 2001)

B. Special-purpose simulation

**Definition:**

This simulation deals with the methods developed for specific domains in construction. These domains include tunneling, earth-moving, piping, and others.

**Main developed engines, modeling tools and/or languages:**

1) STEPS (McCahill and Bernold 1993)

2) RBS (Shi and AbouRizk 1997)

3) The AP2_Earth simulation engine (AbouRizk and Hajjar 1997)

4) The CSD simulation engine (AbouRizk and Hajjar 1997)

5) The CRUISER simulation engine (AbouRizk and Hajjar 1997)

## 2.4. ANALYSIS OF CONSTRUCTION SIMULATION REVIEW

Our focus in this analysis is on the various types of simulation engines and/or languages used according to the objects to be modeled. There are three analysis tools used for that. The first analysis tool was based on defining construction applications areas for simulation. The main construction areas that have been covered by simulation in the construction engineering and management field were collected through a survey done for

the period from 1992 to 2001 (Elghandour and AlHussein 2003) as shown in appendix 1 and are as follows:

1) Construction Process/modeling
2) Cost Control
3) Equipment Management
4) Estimating
5) Human Performance
6) Information Gathering
7) Integration System
8) Labor Management
9) Lean Construction
10) Materials Management
11) Performance Evaluation
12) Planning
13) Productivity Management
14) Resources Management
15) Rework
16) Risk Management
17) Scheduling
18) Time control

The second analysis tool is used based on the main functions of construction simulation engines and/or languages according to the objects to be modeled, as shown in table 2.1. The third tool was the tracking of the developed simulation engines and/or languages

during the period from 1976 until 2002, according to various types as shown in Figure 2.3. Based on these analysis tools, it was clear that many application areas in the construction discipline, such as change orders, constructability, quality control and others have not been taking advantage of simulation as a powerful decision support system until now. As well, it was noted that simulation models were not able to transfer data well with other software applications, for areas that have been covered in construction, or with other simulation models developed in other areas. Also there were no flexible generic elements that could cover all types of data that need to be transferred. At the same time, it seems that there was a trend for designing simulation models based on the process or activity element until 2002, while resource-based simulation engines started in 1987 with Paul et al. and have been taken care by researchers during the period from 1992 to 1994 with sudden drop till 2000 when ABC was introduced by Shi (2000). Concurrently new trends in simulation such as product-based and function-based approaches have been introduced. We think that these new trends will receive more interest from R & D during the coming decade. As well, a new approach that is flexible enough to change its main entity type according to the requirements of the developed model, so that it can be resources in one model and products in another one or a combination of them and so on, is needed. The new approach would not need for any entity to be processes. The following main results are also noticeable from table 2.2:

1) There is always entity generated in all types.
2) All types do not support completely model reusability.
3) All types do not support all information abstraction levels.
4) Complexity is one of main criteria for all types.

5) Only the function-based type can engage new elements during simulation run, but it is limited to rules specified for each element.

6) Also the function-based type is the only type that has the ability to change attributes dynamically during a simulation run, as well as allow both autonomy and integrity.

7) Integration with other applications has not been achieved yet.

8) Full tracking of life cycle and states for all elements have not been achieved yet.

9) All types do not support dynamic changes of entity type or differentiate between various types of resources.

10) Activity-based and product-based types enable planning relations between construction activities, while the process-based type could probably enable that.

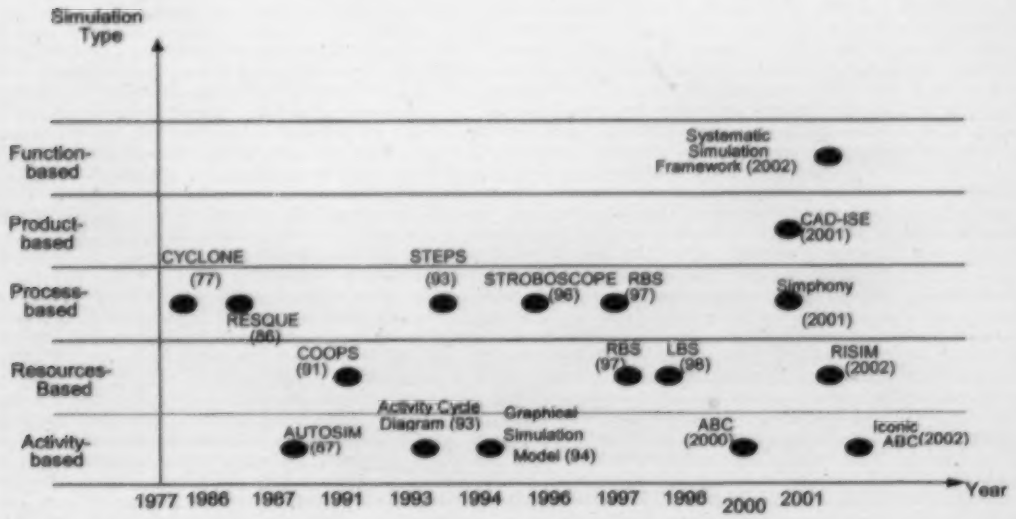



**Figure 2.3 : History of Construction Simulation Models**

**Table 2-1 : Comparison between Functions of various Construction Simulation Engines and/or Languages according to Objects to be modeled**

| Item number | Functionality | Activity-Based | Resource-Based | Process-Based | Product-Based | Function-Based |
|---|---|---|---|---|---|---|
| 1. | Generate entities | entities can be generated by activity | entities can be generated by r-process element | Separate Element or Queue Element | Entity modeling element and outside element | Any element |
| 2. | Terminate simulation | Simulation time or production cycle of selected activity | Simulation time | Simulation Time or Entity Count | Simulation Time or Entity Count | Simulation Time or Entity Count |
| 3. | Support Model Reusability | Support partially | Support Partially | Doesn't Support | Support Partially | Support Partially |
| 4. | Abstraction Level | Activity Level | Resource Level or Process Level | Process or Task Level | Product and task level | Task level |
| 5. | Complexity | Almost Simple | Partially complex | Almost Complex | Complex | Complex |
| 6. | Engagement of new elements during simulation | Not available | Not available | Not available | Not available | Available |
| 7. | Resource location | Activity or pool | Pool (huge one for required and not required resources) | Waiting location or pool | Declaration Modeling element | No specified location |
| 8. | Dynamically change elements attributes | Not available | Not available | Not available | Not available | Available |
| 9. | Allow autonomy of elements | Not available | Not available | Not available | Not available | Available |
| 10. | Allow integrity of elements communication | Not available | Not available | Not available | Not available | Available |
| 11. | Integration with other applications | Not available | Not available | Not available | Partially available | Not available |
| 12. | Tracking life cycle of construction elements | Not available | Not available | Not available | Only product elements | Not available |
| 13. | Trace changed states of elements | Only resources | Only resources | Only resources | Only product elements | All elements |
| 14. | Entity type is dynamic | Doesn't support | Doesn't support | Doesn't support | Doesn't support | Doesn't support |
| 15. | Differentiate various types of resources (consumable, reusable.. ) | Doesn't support | Doesn't support | Doesn't support | Doesn't support | Doesn't support |
| 16. | Enable planning relations between activities | Enabled | Not enabled | Probably enabled | Enabled | Not enabled |

## 2.5. REVIEW OF CONSTRUCTION INFORMATION MODELS

This section introduces several conceptual information models of construction modeling. Wix (1997) defined Information Modeling as the process in which a model seeks to capture the ideas inherent within an area of interest together with relationships (expressed as facts or business rules) which exist between those ideas. Conceptual models are used in modeling the information of a specific domain or the content of a database, describing the semantics of this information, but not its format. There are various modeling techniques used for defining conceptual models. Each one is based on a specific data model, which provides concepts or tools for describing data, data relationships, data semantics and the constraints of conceptual models such as IDEF1X, NIAM, and EXPRESS. At the start of the integration of information modeling in the construction industry in the late 80's, the main concentration was focusing on CAD integration. Recently more R & D projects have been developed to secure information modeling integration within the construction industry.

Stumpf et al. (1996) classified what has been developed for information modeling in the construction industry as product, process, and project models. They defined the product model as a conceptual structure used to organize and communicate building product information among the project participants. While Tolman (1999) defined the product model as an information model that implicitly contains data regarding the form and functional behavior of a product and is able to describe the product through its life cycle. The Process model represents important steps throughout a project's life cycle. According to IDEFO (Sanvido 1990), the process could be explained as information used by the process as input controlled by one or more controls that constrain the way in

which the process may be undertaken. The process may be undertaken by the use of one or more mechanism and, at the end of the process, it delivers information as output. The project model provides a framework for the system integration of product, process, and organizational aspects. Examples for each type were mentioned, including the General Reference Model, STEP and RATAS for the product model, the Integrated Building Process Model and General Data-Flow Model for the process model, and the Unified Approach Model, GenCOM, BPM, and IRMA for the project model. Although the integrated construction information model ICIM (Stumpf et al. 1996) has been developed, it lacks the level of details that are essential for any construction simulation model to be developed. They stopped at the level of activity definition and did not extend their level of information to the sub-activities and tasks. Three levels for identifying construction activities were determined. These levels are the organizational level, including only key project activities, the project level, including more detailed activities, and the process level, which includes increasingly detailed activities such as excavation, hauling, dumping, and waiting. They limited their research to the project level, which is not enough for the construction simulation information integration model.

Another set of classifications for information modeling, and its applications within engineering, is defined by Cutting-Decelle et al. (1997). They order it as product, activity, and resource models. They mentioned that the intersection between the product model and the activity (process) model should be dynamic and exist in terms of time and space. Slaughter (1998) distinguished three types of construction information in her process simulation model: the process flow, project specifics, and project dynamics. The main unit of analysis in her models was the specific element or component being acted

upon. Although the objective was clear and well-defined, the interaction between the elements of construction was not, especially between the process and the final product. Froese et al. (1998) mentioned that representation of construction methods is closely tied to the three most fundamental entities, the representations of the construction products, the processes, and the resources used by the processes. He made distinctions between the representations of specific products, processes, and resources used in a particular construction project and those of general construction projects. Two of the main efforts made in terms of the organization of construction information modeling are STEP and IAI. The main purpose of STEP is to produce many standard product models, to be used within each specific area of construction, called Application Protocols (AP's). Part 106 (BCCM) of the STEP building construction group consists mainly of process objects, product objects, resource objects and control objects. Again, the process objects were also limited to the higher levels of processes, and did not extend to the lower levels of sub-processes or tasks. The Industry Alliance for Interoperability (IAI) is a consortium of building product suppliers, architects, engineers and software companies dedicated to producing standardized Industry Foundation Classes (IFC's). Tolman (1999) stated that the IAI-IFC is not really a standard, rather it is an Application Programming Interface (API), providing product modeling functionality (as a set of C++ classes) to CAD vendors that want to base their future software on these classes. He added that the construction industry still does not know how the integration problem can be solved until present. Cuttting-Decelle et al. (1999) mentioned that the integration of the product and process models will help to overcome the problem of fragmentation in the construction

industry by enabling construction project teams to collaborate through a shared project model. This was one of the main objectives for their project ProMICE.

Many challenges are still facing construction information modeling. These challenges include finding solutions that are responsive to the wide variety of existing and emerging models for different applications. These models are able to not only model the information but translate information among the different applications as well Froese (1996). Other challenges are the lack of testing for developed models Bjork (1999), and the full integration of product and process models Cutting-Decelle et al. (1999). As well, there is the issue of developing one single general data model for all Amor and Faraj (2001).

They determined that developing and using one single data model in the construction industry is not feasible. Developing aspect information models for each specific area within the construction industry is improbable for the same reasons mentioned, such as the enormous range of information, the large number of objects to be modeled, the lack of ability to model all documents, and reconciling different views. The industry needs a new approach with the capability to capture all the elements in a systematic and standard way, relative to their interdependencies in the construction. In addition to this, the new approach must be able to integrate with any decision support system in a standardized and flexible way.

## 2.6. ANALYSIS OF INFORMATION MODELS APPLICATIONS REVIEW

During our survey for construction information modeling, we noticed that seven main classes exist according to their main objectives and main project coverage areas. These classes, with some examples, are described here:

1) Models developed for describing only the process model at the design phase, such as the CRPM model by Kamara et al. (1999).
2) Models developed for describing only the product model during the design phase, such as Object-Oriented Model Management OOMM (Lammer et al. 2001), and ID'EST (Kim et al. 1997).
3) Models developed for product and process integration at the design phase only, such as: ProMICE (Cutting-Decelle et al. 1999) and the STAR project (Hannus et al. 1997) which places emphasis on improving the construction process more than the product and process integration and knowledge based information model for components in the process industry (Arnold and Teicholz 1996).
4) Models developed for describing only the process model at the construction phase, which can be supported by a product data model such as Project Modeling in Construction Applications (Froese et al. 1996), the Construction Core Model (CCM) (Dado 1998), Planning the Construction of a building using the GCLA language (Aronsson 1993).

5) Models developed for product and process integration at both the design and construction phases, such as ICIM (Stumpf et al. 1996), IRMA (Luiten et al 1993), BPM (Luiten 1994), and the AEC Core Model (Froese 1996).
6) Models developed for the integration of the product and process models for the integration of project management applications, such as GenCOM (Froese 1992), and PMIC (Shahid 1996).
7) Models developed for the integration of all the project objects of a project during its life-cycle such as the Unified Approach Model, ICON, the Building Project Model, ATLAS, GRM, PISA, and the STEP Building Construction Core Model.

Three main analysis tools have been used to Figure out the prevailing trends and limitations of existing construction information modeling. The first tool is to track the history of construction information modeling (Figure 2.4). The second tool involves comparing these models based on main modeling functions (table 2.2). The last analysis tool with assistance from a survey done on the main ITC journals during the period from 1992 to 2001 (Elghandour and AlHussein 2003) was defining the main construction areas that have been covered by information modeling. These areas are as following:

1) Scheduling
2) Estimating
3) Cost control
4) Change-order tracking
5) Materials tracking

6) Resource management

7) Equipment management

8) Inventory control

9) Purchasing/supplier management

10) Engineering and surveying support

11) Quality management

12) Productivity management

13) Risk management

14) Lean construction

15) Planning

16) System Integration

17) Safety management

18) Construction methods/process/planning

19) Site planning

20) Rework

21) Delay management

22) Time control

23) Client Satisfaction

24) Contractors/subcontractors evaluation

25) Dispute management (Resolution)

26) Claim management

27) Performance evaluation

28) Environmental management system

29) Human performance

30) Daily site reporting

31) Site investigation

32) Maintenance management

33) Labor management

34) Data acquisition

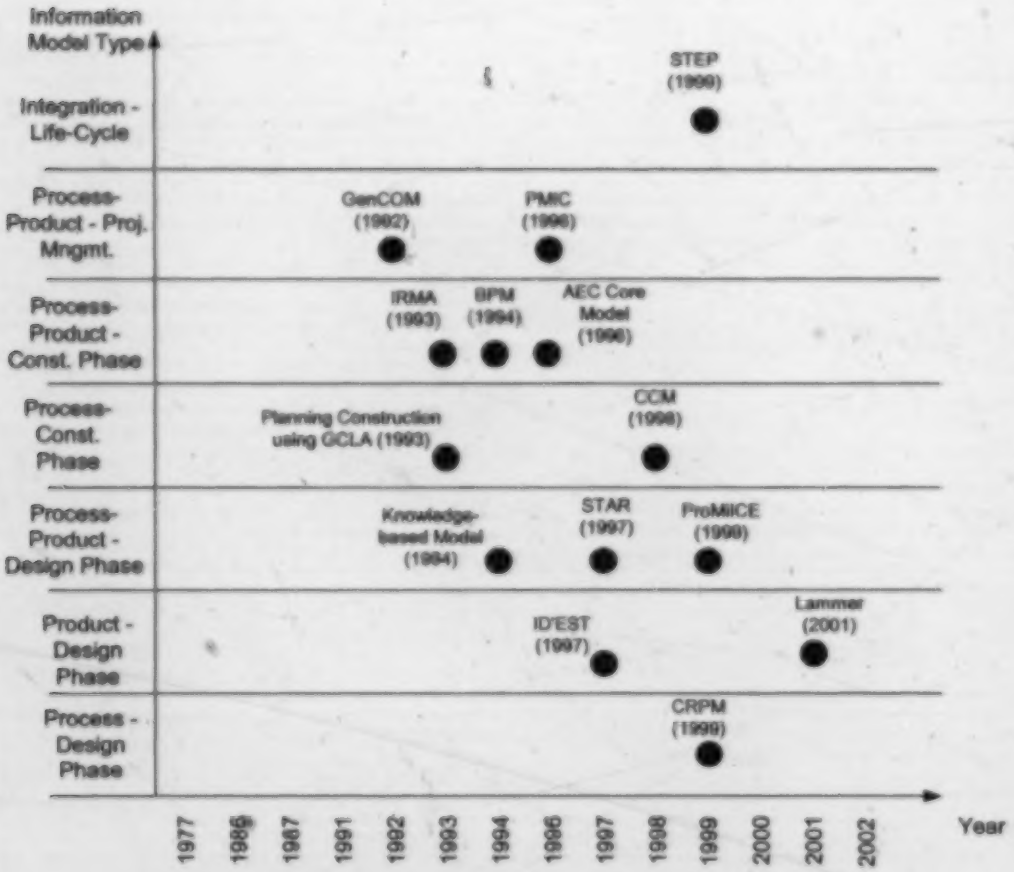



**Figure 2.4 :History of Construction Information Modeling**

**Table 2-2 :Comparison between various Construction Information Models Functions**

| Item number | Functionality | Process-Based | Product-Based | Integrated Product – Process Based |
|---|---|---|---|---|
| 1 | State Representation | Partially supported for product at activity level | Not supported | Partially supported for product at activity level |
| 2 | Resource Representation | Supported | Not supported | Partially supported |
| 3 | Document Representation | Partially supported | Partially supported | Partially supported I |
| 4 | Function Representation | Not supported | Not supported | Not supported |
| 5 | Automated Engagement of new elements after modeling | Not supported | Not supported | Not supported |
| 6 | Allow integrity of elements communication | Partially supported | Partially supported | Partially supported |
| 7 | Tracking life cycle of construction elements | Partially supported | Partially supported | Partially supported |
| 8 | Differentiate various types of resources (consumable, reusable ...) | Not supported | Not supported | Not supported |
| 9 | Abstraction level | Process level | Product level | Process level |
| 10 | Enabling planning relation between activities | Supported | Not supported | Supported |
| 11 | Define various types of states | Required, purposed and realized states only | Required, purposed and realized states only | Required, purposed and realized states only |

It is clear from this analysis that the state of construction elements is still not completely represented in construction information models, along with some other criteria such as: document, function, tracking life cycle, various type of resources, and various types of

states. Also the engaging of a new element after modeling and complete integration between elements are still not completely represented.

## 2.7. COMPARATIVE STUDY

In this section both simulation and information models developed for construction will be compared. In order to do that we will use for that diagrams developed using EXPRESS-G graphical notation (Figures 2.4 and 2.5). These diagrams are a formal representation of the nature, sources and interrelationships between the information required for the implementation of developed construction information models and simulation models. This has been introduced to simplify the comparative study and analysis of the tools.

From the outset, the comparison of both types of modeling made it clear that the range of areas for applications of information modeling is wider than that of simulation modeling. This observation seems logical due to the acceptance of information modeling within construction prior to simulation modeling. Also, the significant support that is offered for information modeling from many associations and software companies encouraged those in R & D to offer and cover most application areas of the construction sector. In addition to these reasons, simulation modeling needs construction engineers that understand the packages developed for it, while for information modeling, the models are hidden in the software, which requires little to no effort on behalf of the user to understand it. By comparing the two EXPRESS-G conceptual information model diagrams, as shown in Figure 2.5 and Figure 2.6, it was clear that information models contain a variety of elements. At the same time, simulation models do not extend their definitions to

accommodate these varied elements including contract, control object, organization object, management object, actor, result, method, component, construction plan, and actions activity elements. This lack of element inclusion hindered the reliability of simulation as well as its ability to communicate with other construction applications.

The abstract level for information models did not extend beyond the activity (highest level) or process level (Medium Level); while the abstract level for simulation models extends to the task level (lowest level). Simulation models extended their definition to include function, resource, and activity, in addition to the process and product, as main objects running in the models. Information models, however, used only the process and product objects as the core objects in developing their models. The information models were able to define most of the relationships between the various components and elements of construction, while the simulation models were unable to accomplish that well. The information models were more realistic in defining the breakdown structure of construction activities, or work objects, than the simulation models. This ability allowed the information models to communicate well with most applications of construction, especially the cost estimating and cost control applications. Although simulation models dealt with many core objects, all of these models were primarily dependant on the process entity, and its sublevel (tasks) or super level (activity), and did not deal with the product in the same way the information models did. While some effort was made to integrate construction simulation with other construction software, such as the system developed by Wickard et al. (1989) that presented a system to link simulation with the CAD system, the gap still exists.

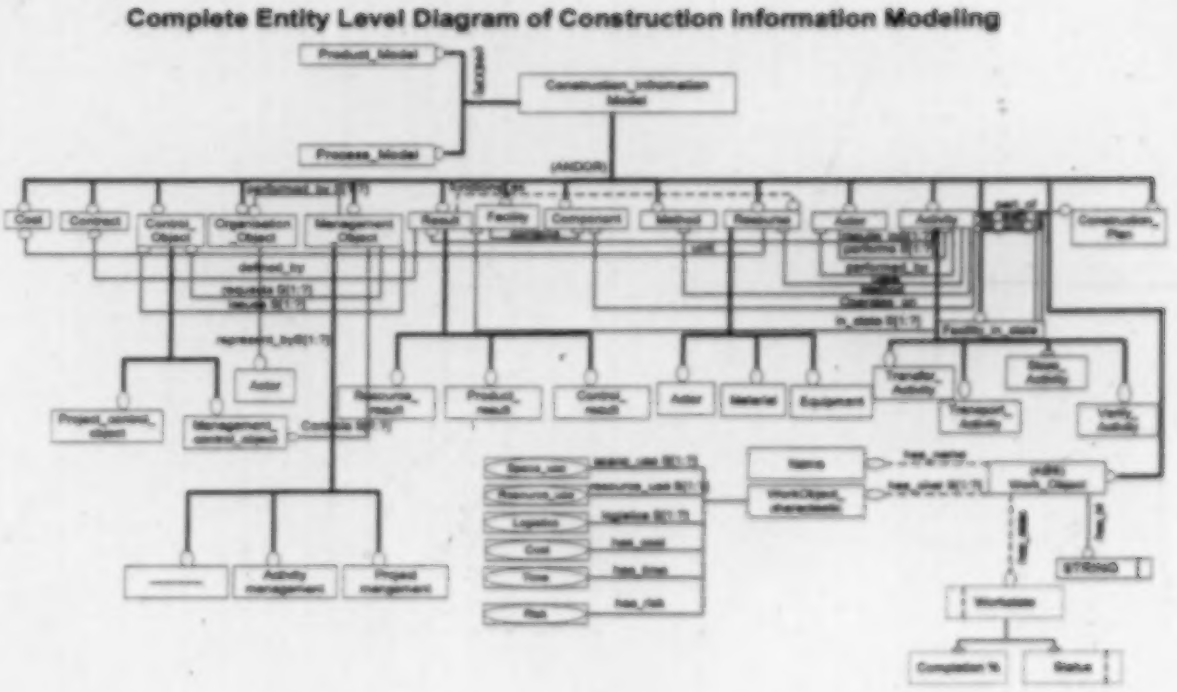
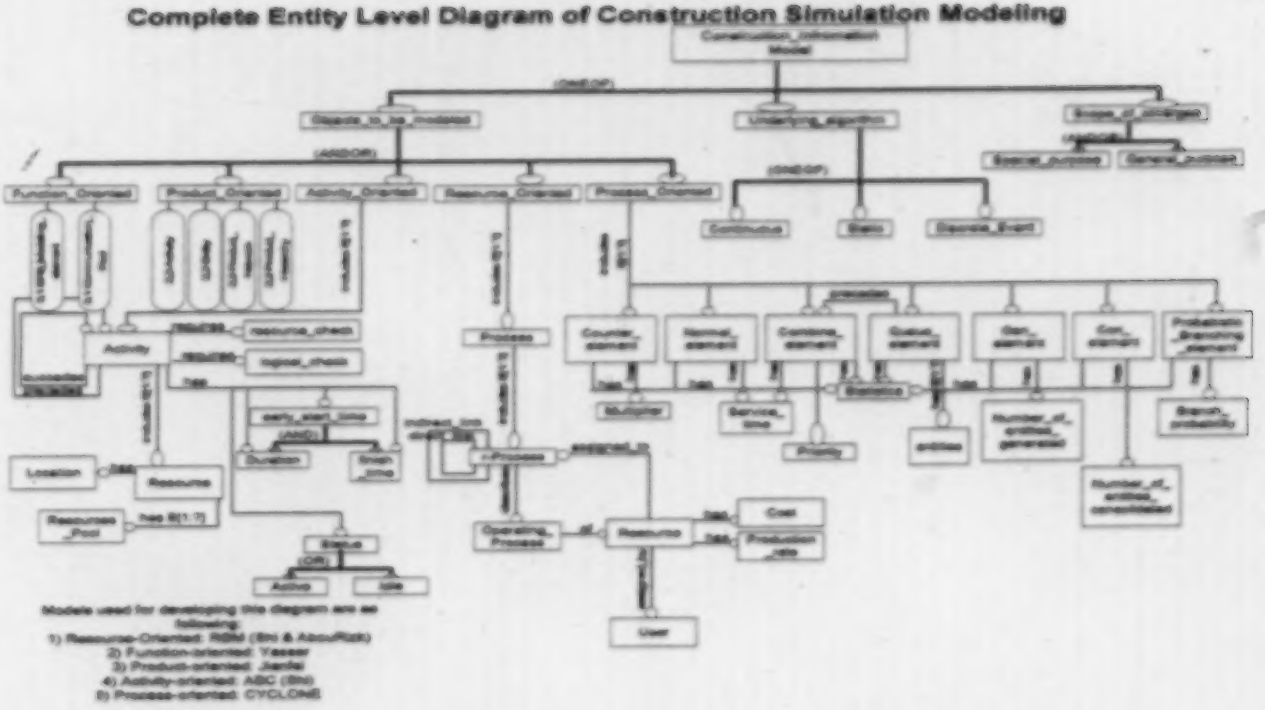
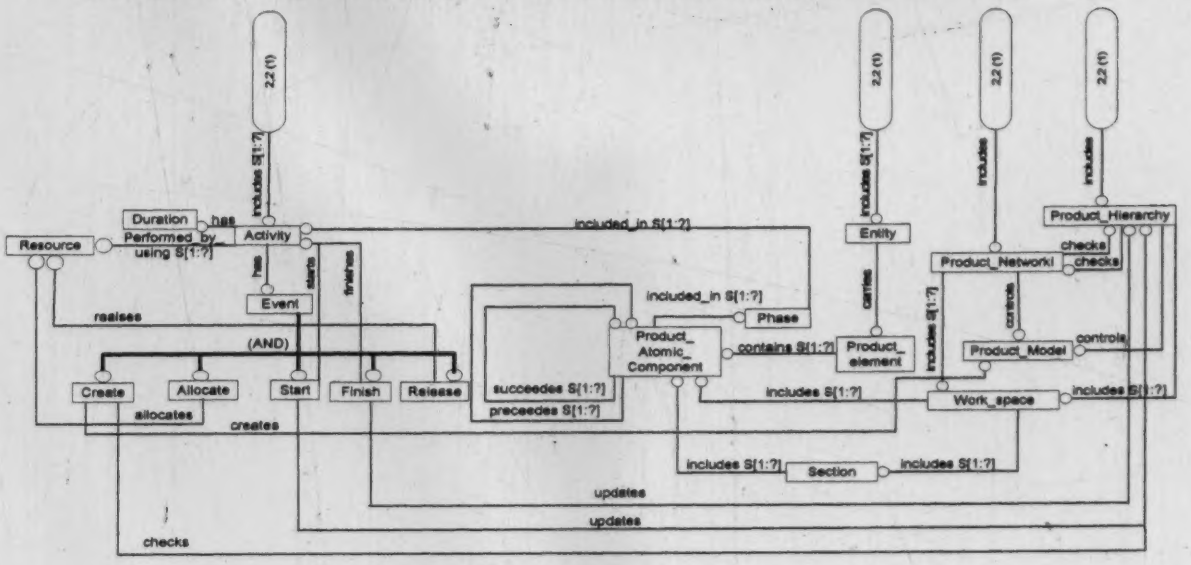



**Figure 2.5 :Construction Information Models View Model using EXPRESS-G**



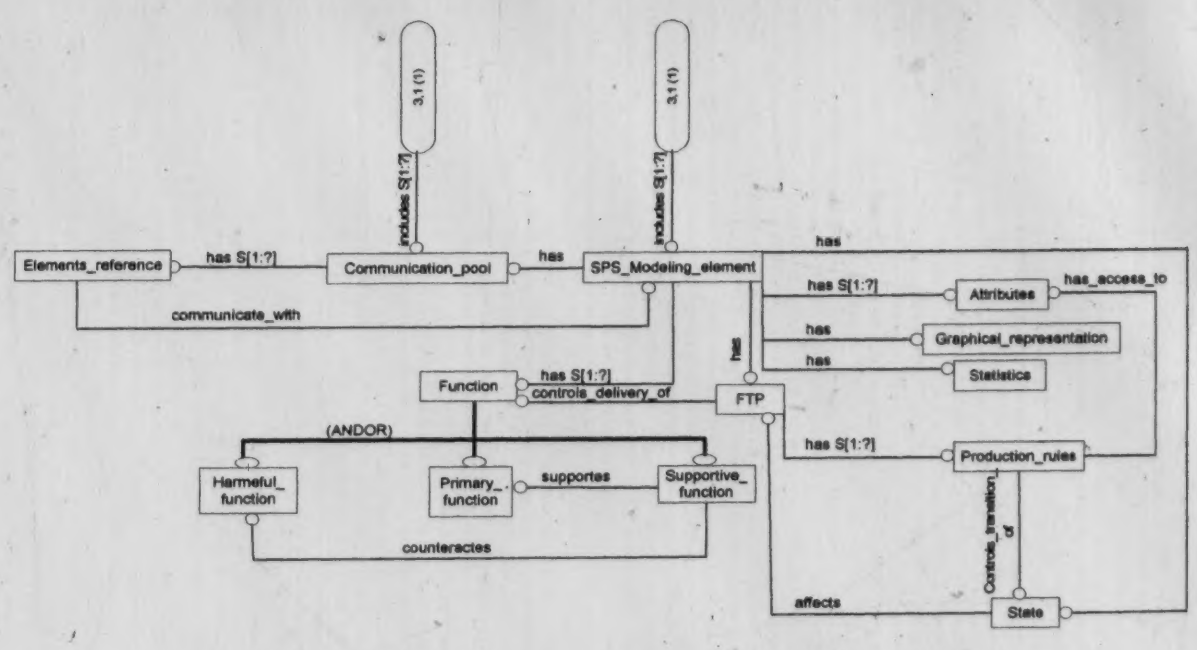

a) : Construction Simulation Models View Model using EXPRESS-G

**Complete Entity Level Diagram of Construction Simulation Modeling**




**b)** : Construction Simulation Models View Model using EXPRESS-G

**Complete Entity Level Diagram of Construction Simulation Modeling**




c) : Construction Simulation Models View Model using EXPRESS-G

**Figure 2.6 : Construction Simulation Models View Model using EXPRESS-G**

It is clear from this comparison that the information gap between construction simulation and other construction decision support tools, along with other design and construction software, still exists, as shown in Figure 2.7. The construction information models developed to date are static, which means they cannot reflect the dynamic nature of this discipline. On the other hand, construction simulation engines developed to date represent well the dynamic nature of this discipline but lack the exchangeability and the flexibility criteria.

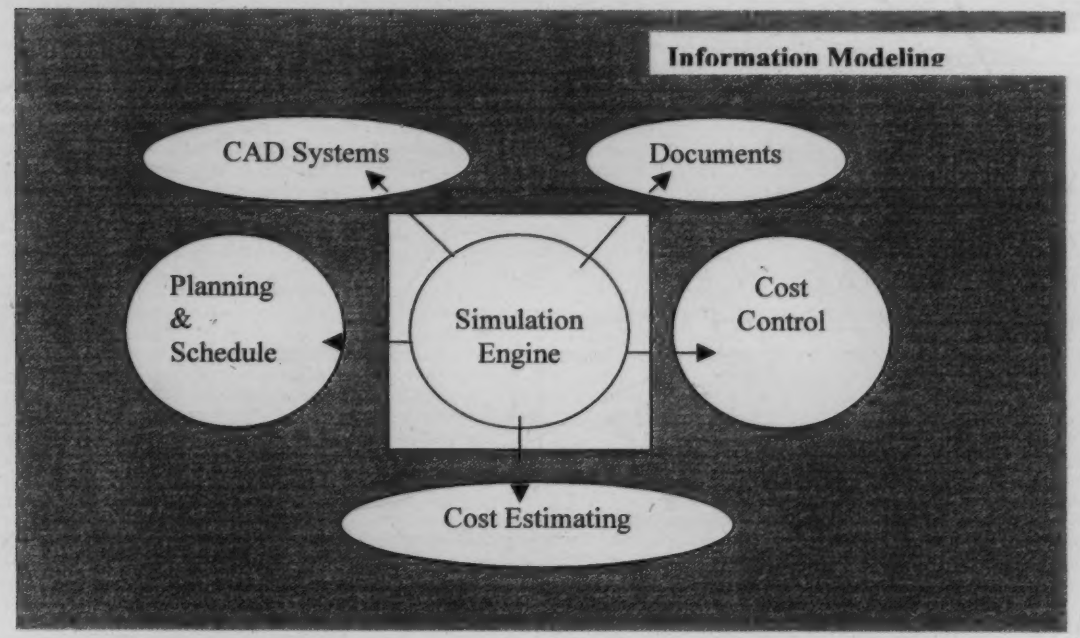



**Figure 2.7 : Fragmented information flow between simulation and construction management areas**

## 2.8. FUTURE RESEARCH NEEDS

In this section, an agenda for the coming years of Information-Simulation integration in the construction discipline is introduced. There is still a gap in the R & D for the

development of appropriate information-simulation integrated models for the construction phase of the project. And there is a need to ensure the reusability of models to avoid both duplication and the waste of resources. In the RBS model for example, Shi and AbouRizk (1997) built atomic models of sub-processes, but these models were not reusable and very complex due to the uniqueness of the construction projects. And they did not contact the depth of construction information at its lowest abstract level. Also O'Brien (1996) defined data integration as the merger or amalgamation of symbolic representations of states of affairs in the world, such that the representations can satisfy the needs and requirements of a number of diverse users. He defines two approaches to achieve that goal, first the data flow, and second the data sharing. In our opinion, this type of integration should be established through a set of carefully designed new information models. O'Brien mentioned that the processes needed to produce the output in the construction industry are non-repetitive, and that each one is essentially unique, and the author partially agrees with him. But if we deeply investigate that, it is easily noted that these processes are fixed in their nature at their lowest abstract level (tasks), and fixed in their interdependences with other information elements in construction.

The need for a new approach involving the representation of construction information at all levels, as related to simulation modeling, is becoming greater. This approach should be flexible, powerful, and capable of integrating well with any other construction decision support tools. The developed system should be able to incorporate the information modeling within simulation engines in a generic environment to ensure workflow and deal with uncertainty and flexibility. The approach should be clear and straightforward in its terminology in order to gain acceptance amongst the construction

industry participants, and should distance itself from complicated methodologies. As well, the approach should try to keep the construction information obvious for application across all decision support systems, and stay away from the information desertification approaches being used now, to give them more credibility and reliability. The approach should be able to achieve the goals outlined in table 2.3 for the construction discipline.

One of the main requirements for this new system or approach is that it be flexible enough to expand at anytime. New construction methods, materials, equipments, and actors are introduced each year. This means that this new system should be prepared to accommodate the addition of new data items at anytime. The approach should allow the user to smoothly identify the project logic without the need to hire a simulation developer, in the case of sudden changes that require a quick response. The approach should have a type of pre-built constructs at the lowest abstract level of the construction. The design at the lowest abstract level will enable the engine to overcome the problems of special purpose or library-based simulation models, and the IFC problems of information modeling. In both cases, the problem of fixed structure at some levels (resource, process, product, or function), does exist. This Fact restraints the breadth of their application and interaction due to the issue of complexity and apparent uniqueness. According to Halpin and Woodhead (1976), construction management has, in general, four levels of hierarchy or abstractions: the organizational level, the project level, the activity level, and the process level. These levels are important in the data tracking in simulation models. Figure 2.8 describes some information elements at these levels, and the information flow that exists between these elements.

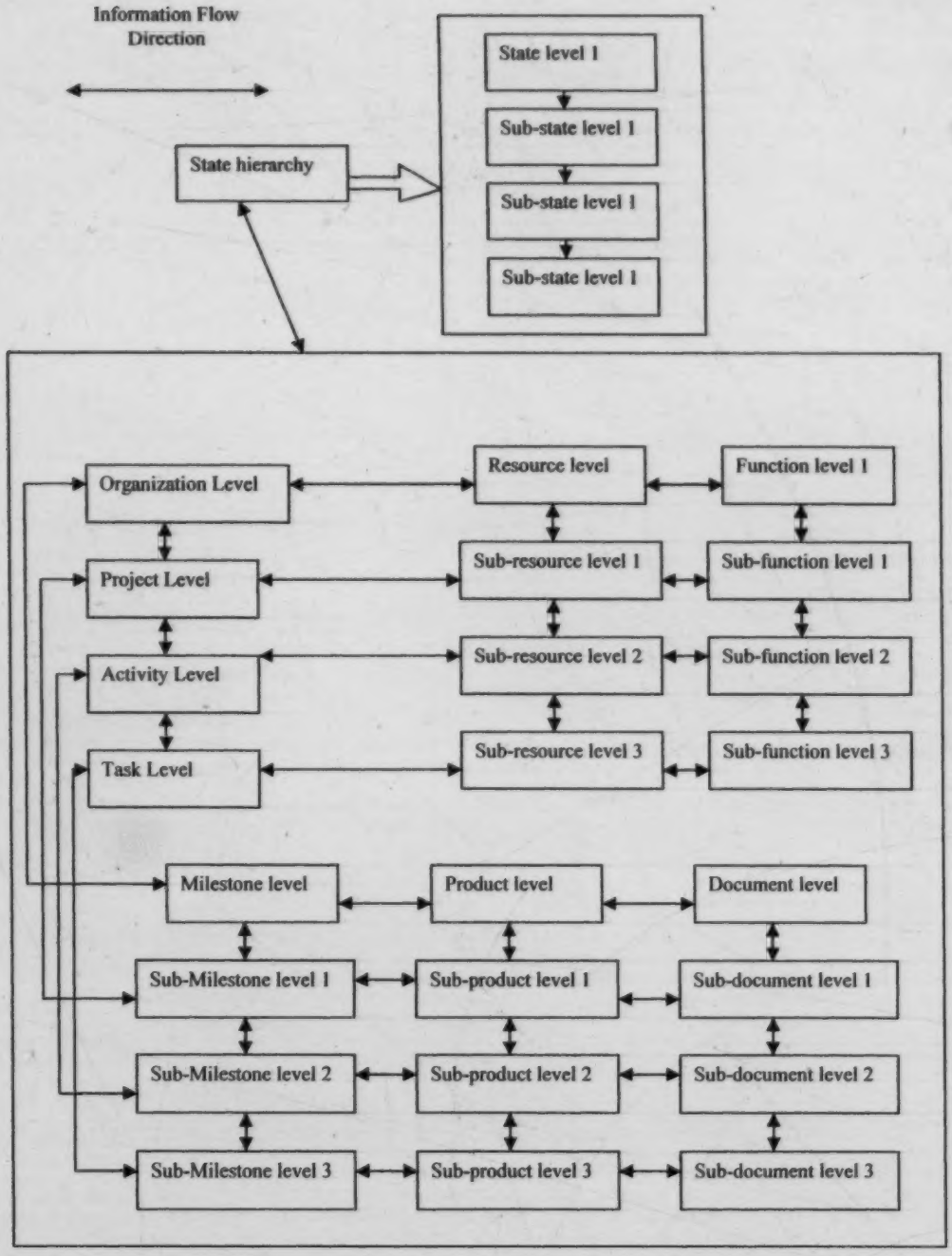



**Figure 2.8 : Proposed abstraction levels hierarchy for construction management.**

The approach should also provide the user with an effective way of choosing the required elements, along with their relationships, and of building the required model easily and correctly. The approach should be able to analyse the output data of the simulation modeling within any other decision support tool. Decreasing the need for programming is another criteria that should be met in order to increase the credibility of this approach. Versionality is another important factor that should be established to increase the flexibility of this approach, as well as its ability to track and record the various states of any construction element during its life-cycle. Another important factor in making this approach acceptable is ensuring the use of the same ontology as the one used in the construction. The model should be able to change the focus of the simulation from the physical components of the construction, and their required tasks and resources, to include all its other elements, such as actors, products, management objects, and documents. The system should be able to describe all of these elements and their interactions with the outer environment and inner environments. The construction data should be described in-depth in order to be ready for system integration. One of the main sources that this author believes these criteria could be found in, which could help solve the problematic design of this approach, are the natural laws that control the flow of information in our lives. An example of this is the chemical and physical laws that control the interactions between atoms and chemical elements. If these or similar approaches were analysed carefully, a new system for the control of information flow in the construction discipline could be established. This could be reflected in simulation

modeling and other decision support systems, and it could even extend, it affects other information flow environments.

This new proposed system should be a conceptual model that provides necessary structures and describes how information about the construction elements should be organized. Suitable modeling language could be used for that, such as NIAM, IDEF10, or EXPRESS and its graphical representation language EXPRESS-G.

This system, as we imagine, should be able to sort elements of the construction discipline into static classifications according to their response to the information the other elements and themselves. These different classes could be the same for all construction projects.

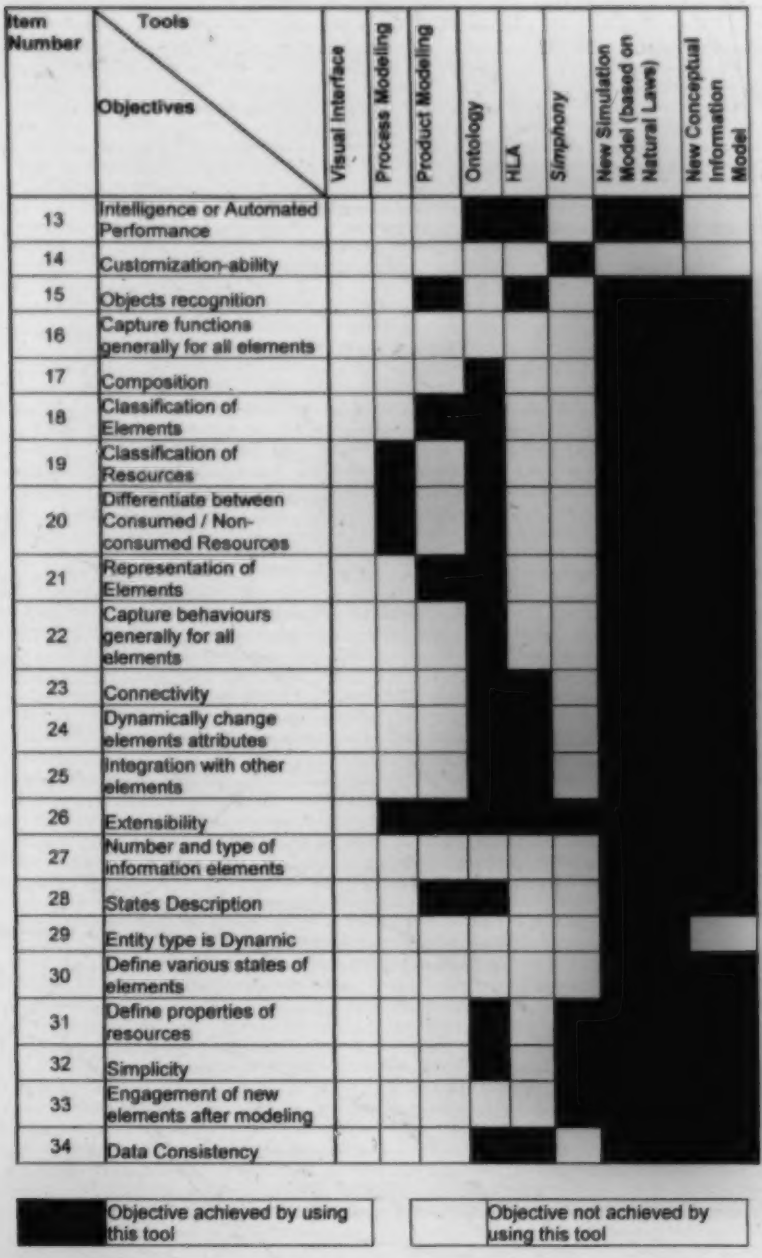
Other criteria that should be taken into consideration when choosing or developing a new system include the type of information elements, and their identification, composition, connectivity, versioning, fulfillment, representation, characterization, states, and extensibility as described by Froese (1996). Table 2.3 describes these criteria along with others necessary for establishing this integration. One of these criteria is the ability of this model to distinguish between the various types of resources (disposable [consumable], and reusable [durable], and the department of the company. Another criterion is to define the states for objects or entities, which is suitable for both simulation (active, idle) and information models (required, proposed, and realized [Luiten 1994]). Two other criteria for this model are that they need to be dynamic and able to define all entities that play a role in construction. Froese (1996) suggested five types of information elements: physical entities, logical entities, processes, associations, and characteristics. To achieve our goal, the following types are more suitable: resources,

actors, products, tasks, activities (processes), states, functions, methods and documents. The objectives and criteria required for this system, along with the proposed tools required to achieve them, are described in table 2.3. One tool is High Level Architecture (HLA), which is a standard approach that supports distributed simulation. HLA will be used in supporting and designing this environment. The use of HLA can achieve the two missing desirable properties of existing construction simulation models: reusability and interoperability. Another tool is the unified simulation environment, *Simphony*, developed by Dany and AbouRizk (2000).

We believe that the most significant development that will occur during the next decade, in the area of construction simulation modeling, is its integration with other construction applications through information modeling.

**Table 2-3 : Matrix of Objectives vs. Tools for Integrated Information-based Simulation System**

| Item Number | Tools / Objectives | Visual Interface | Process Modeling | Product Modeling | Ontology | HLA | *Simphony* | New Simulation Model (based on Natural Laws) | New Conceptual Information Model |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Credibility | ■ | ■ | ■ | ■ | ■ | □ | ■ | ■ |
| 2 | Reliability | □ | ■ | ■ | ■ | □ | □ | ■ | ■ |
| 3 | Reusability | □ | □ | □ | ■ | ■ | ■ | ■ | ■ |
| 4 | Interoperability | □ | □ | □ | ■ | ■ | □ | □ | □ |
| 5 | Controllability | □ | □ | □ | ■ | ■ | □ | ■ | ■ |
| 6 | Understanding Construction Processes | □ | ■ | □ | □ | □ | □ | □ | ■ |
| 5 | Information Sharing | □ | □ | □ | ■ | ■ | □ | □ | ■ |
| 7 | Cover-ability or flexibility | □ | □ | □ | □ | ■ | □ | ■ | ■ |
| 8 | Versionality | □ | □ | □ | ■ | □ | □ | ■ | ■ |
| 9 | Dynamic | □ | ■ | ■ | □ | ■ | □ | ■ | ■ |
| 10 | Detailed | □ | ■ | □ | □ | □ | □ | □ | ■ |
| 11 | Inheritance | □ | □ | □ | ■ | ■ | ■ | ■ | □ |
| 12 | Product and Process Integration | □ | □ | □ | □ | □ | □ | □ | ■ |




## 2.9. CONCLUSIONS

In this paper, the main discussion has been around the applications of information and simulation modeling in construction. It starts with reviewing these applications, compare

them, and identify potentials of their integration. A strategy for future research to achieve this integration has been introduced. It includes detailed description of various objectives and proposed tools that can be used to complete this mission. The shortage of existing simulation models capabilities was also discussed and declared. Another three papers will be introduced to investigate this approach by using proposed tools.

## 2.10. REFERENCES


- AbouRizk, S.M., and Hajjar D. (1998). "A framework for applying Simulation I Construction." Can. J. Civ. Eng., 25, 604-617
- AbouRizk, S.M., Halpin, D., and Lutz, J. (1992). "State-of-the-art in construction simulation." Proceedings of the 1992 Winter Simulation Conference, ASCE, Arlington, Va., December, pp. 1271-1277.
- Amor, R., and Anumba, C.J. (1999). "A Survey and Analysis of Integrated Project Databases." Concurrent Engineering in Construction Conference.
- Amor, R., and Faraj, I. (2001). "Misconceptions about Integrated Project Databases." Journal of Information Technology in Construction, 6 (2001) 57-68.
- Arnold, J. A., and Teicholz, P. (1996). "A Knowledge Based Information Model for Componets in the Process Industry." Congress on Computing in Civil Engineering Proceedings 586-592.
- Aronsson, M. (1993). "Planning the Construction of a Building." Swedish Institute of Computer Science, ISSN 0283-3638.
- Au, G., and Paul, R.J. (1994). "Graphical Simulation Model Specification based on activity Cycle Diagrams." Computing Industry Engineering, 26(2), 295-306.
- Bortscheller, B. J., and E., T., and Saulnier (1992). "Model Reusability in A Graphical Simulation Package." Proceedings of the 1992 Winter Simulation Conference, 764-772.

- Bjork, B-C. (1999). "Information Technology in Construction: Domain Definition and Research Issues." International Journal of Computer Integrated design and Construction, 1, No. 1, pp 3-16.
- Chua, D.K., and Li. G. M., (2001). "RISim: Resource-Interacted Simulation Modeling in Construction." Journal of Construction Engineering and Management", 128(3), June, pp. 195-202.
- Cutting-Decelle, A-F, Dubois, A-M, and Fernandez, I. (1997). " Management and Integration of Product Information in Construction: Reality and Future Trends." The International Journal of Construction Information Technology, Vol 5, No 2 Page 19-46.
- Cutting-Decelle, A.F., Anumba, C.J., Baldwin, A.N., Bouchlagbhem, D., Dufau, J., and Mommessin, M. (1999). "Information of Concurrent Engineering Concepts into Integrated product and process model." Concurrent Engineering in Construction Conference.
- Dado, E., and Tolman, F.P. (1998). "Support of Site Construction Processes by Product Data Tecnology." Proceedings CIB Conference.
- Dado, E., and Tolman, F.P., (1999). "Proposal for an Integrated Information Model for Concurrent engineering of On-site Construction." International Conference for Engineering Concurrent.
- Elghandour, W., and AlHussein, M. (2003). "Survey of Information Technology Applications in Construction." Journal of Construction Innovation.
- Froese, T. M. (1992). "Integrated Computer-Aided Project Management through Standard Object-Oriented Models." Ph.D., Stanford University, June.
- Froese, T. (1996). " Models of Construction Processes Information." Journal of Computing in Civil Engineering, Vol. 10, No. 3, July, 183-193.
- Froese, T. (1996)." Models of Construction Process Information." Journal of Computing in Civil Engineering, 10(3), July, 183-193, ASCE.
- Froese, T., and Rankin, J. (1998). "Representation of Construction Methods in Total Project Systems." Submitted to 5th Congress On Computing On Civil Engineering, ASCE, Boston.

- Froese, T., Yu, Kevin, and Shahid, S. (1996). "Project Modeling in Construction Applications." Computing in Civil Engineering: Proceedings of the Third Congress, ASCE, Anaheim, CA, June 1996, pp. 572-578.
- Halpin, D. W., and Riggs, L. S. (1992). "Planning and Analysis of Construction Operations." Wiley, New York.
- Halpin, D. W., and Woodhead, R. W. (1976). "Design of Construction and Process Operations." Wiley, New York, 405- 413.
- Hannus, M., Huovila, P., Lahdenpera, P., Laurikka, P., and Seren, K. (1997). "Methodologies doe Systematic Improving of Construction Processes." 1st International Conference on Computing in Structural Engineering, London.
- ISO (1994). "Industrial Automation Systems – Exchange of Product Model Data – Part 11: Implementation Methods." ISO 10303-11:1994, EXPRESS Language Reference Manual.
- Kamara, J. M., Anumba, C. J., Evbuomwan, N. F., and Hobbs, B. (1999). "An Information Model for Client Requirements Processing in Concurrent Life-Cycle Design and Construction." Concurrent Engineering in Construction Conference.
- Kim, I., Liebich, T., and Maver, T. (1997). "Managing Design Data in an Integrated CAAD Environment: a Product Model Approach." 7(1997) 35-53.
- Lammer, L., Meissner, Udo, and Petersen, M. (2001). "Object-oriented Integartion of Construction and Simulation Models.", Computers and Structures, Elsevier, 79(2001) 2143-2149.
- Luiten, G. (1994). "Computer Aided Design for Construction in the Building Industry." Dissertation presented to Delft University of Technology.
- Luiten, G., Froese, T., Bjork, B-C, Cooper, G., Junge, R., Karstila, and Oxman, R. (1993). "An Information Reference Model for Architecture, engineering, and Construction." Proceedings of the first International Conference on the Management of Information Technology for Construction, Singapore, August.
- O'Brien, M. J., (1996). "A Strategy for Achieving Data Integration in Construction." The International Journal of Construction Information Technology, Vol 4, No 1 Page 21-34.

- Oloufa, A., Ikeda, M., and Nguyen, T. (1998). "Resources-based Simulation Libraries for Construction.", Automation in Construction, 7, pp 315-326.
- Paul, R.J. (1993). "Activity Cycle Diagrams and the Three Phase Method." Procedures, 1993 Winter Simulation Conference, 123-131.
- Paul, R.J., and Chew, S.T. (1987). "Simulation modeling using an Interactive Simulation Program Generator." Journal of Operational Research Society, 38(8), 735-752.
- Sanvido, V.E. (1990). "*An Integrated Building Process Model.*" Technical Report No. 1, Computer Integrated Construction Research Program, Dept. of Architectural Engineering, The Pennsylvania State University, University Park PA.
- Shahid, S. (1996)."Project Management Information Control System", M.A. Sc. Thesis.
- Shannon, R. E. (1975). "System Simulation: The Art and Science." Prentice-Hall, Englewood Cliffs, NJ.
- Slaughter, E.S. (1998). "Phase and Material-Specific Construction Process Simulation Models." Proceedings of the International Computing Congress held in conjunction with 1998 ASCE Annual Convention & Exhibition. PP 379-382.
- Stumpf, A. L., Ganeshan, R., Chin, S., and Liu, L.Y. (1996). "Object-Oriented Model for Integrated Construction Product and Process Information." Journal of Computing in Civil Engineering, 10(3), July.
- Tolman, F.P., (1999). "Product Modeling Standards for the Building Construction Industry: Past, Present and Future." Automation in Construction, 8(1999) 227-235.
- Tommelein, I.D., Odeh, A.M., and Carr, R.I. (1994). "Knowledge Based Assembly of Simulation Networks Using Construction Designs, Plans, and Methods." Proceedings of the 1994 Winter Simulation Conference, IEEE, 1145-1152.

- Wakefield, R.R., and Damrianant, J. (1999). "Petri net modeling – a simulation tool for use in construction process re-engineering." International journal of Computer Integrated Design and Construction, 1(2), pp 20-34.
- Wickard, D.A., Bill, R.D., Gates, K.H., Yoshinaga , T. and Ohcoshi, S. (1989). " Construction CAE: Integration of CAD, simulation, planning and cost control." Proc., American Power Conference, 51, Illinios Institute of Technology research Institute, Chicago, 983-987.
- Wix, J. (1997). "Information Models and Modeling: Standards, Needs, Problems and Solutions." The international Journal of Construction Information Technology, Vol. 5, No. 1, pp 27-38.
- Yu, K., Froese, T., and Grobler, F. (1998). "International Alliance for Interoperability: IFCs.", Proceedings of the International Computing Congress held in conjunction with 1998 ASCE Annual Convention & Exhibition. PP 395-406.
- Zhang, A., and Shi, J. (2002). "Iconic Animation for Activity-based Construction Simulation.", Journal of Computing in Civil Engineering", 16(3), July, ASCE.

# CHAPTER 3. INTEGRATED INFORMATION ARCHITECTURE FOR SIMULATION SYSTEM IN CONSTRUCTION MANAGEMENT

## 3.1. ABSTRACT

In order for users to efficiently utilize the simulation models applications in the construction management industry, a clear definition and architecture is required to organize, classify, and manage the required information. Many simulation models and languages have been developed specifically for construction management but not one of these could totally eliminate the limitations that exist when applying simulation models in this industry. One of these limitations is how these simulation models can easily organize, classify, and manage the required information within its framework. Another significant gap exists in trying to integrate all the information required for construction management applications under the umbrella of a simulation system in a simple, practical approach. At the same time, developed information models in this field did not consider the structure and approach used in developing simulation engines. This paper attempts to create a new and clear definition of construction management information architecture to be used in the development of a construction management simulation system.

## 3.2. INTRODUCTION

Many information models, and simulation models and languages have been designed for the Construction Management (CM) industry. Some examples of simulation models and

languages are CYCLONE (Halpin 1977), RESQUE (Chang 1987), UM-CYCLONE (Ioannou 1989), COOPS (Liu and Ioannou 1992), DISCO (Huang et al. 1994), HSM (Sawhney and AbouRizk 1995), CIPROS (Odeh 1994), STEPS (McCahill and Bernold 1993), STROBOSCOPE (Martinez 1996), and *Simphony* (Hajjar, et al. 1998).

Some examples of information models are the CRPM model by Kamara et al. (1999), the STAR project (Hannus et al. 1997), ProMICE(Cutting-Decelle A.F. et al. 1999), Core Model (CCM) (Dado 1998), ICIM (Stumpf et al. 1996), IRMA (Luiten et al 1993), BPM (Luiten 1994), the AEC Core Model of Froese (1996), and GenCOM (Froese 1992).

Despite this variety of models and languages, two main limitations are still not wholly dealt with. The first limitation concerns how to build a simple simulation system which is generic yet its elements are credible and reliable for end-users. The model should also reflect the actual information that needs to be simulated in the CM industry, and can be distributed so that all decision-makers and end-users, at various levels in any construction project, can view the results of the running simulation model from their perspective alone. The other limitation is how to build a simulation system that can process and produce all required information for all, or at least most, CM management applications, such as scheduling, cost estimate, cost control, cashflow control, risk management, and quality management.

The need to design an information model for a construction management simulation system that achieves these demands and takes into consideration the nature of the CM industry, and its hierarchy information flow, as well as the nature of a distributed simulation system including its structure and inflow of data during its running, is very important.

This paper is based on the results of the previous comparative study between simulation and information models and systems in construction. It first describes the four proposed information abstract levels that are required to access any data in CM environment. It goes on to describe simulation information elements, their roles, the types of roles and the attributes definitions for each abstract level. The design of this model, including its information elements, their roles, and attributes are based mainly on the Ontology development approach proposed by Natalya et al. (2000). The approach is defined in Figure 3.1. consisting of four main steps. The first step is to define the scope and domain of the developed Ontology. It includes developing some general and competency questions and answers to help define the scope and domain, as shown in Appendix 1. The next step includes intensive review and analysis of information models developed for CM and its state-of-the-art, including IFC 2x (IAI 2002), GenCOM (Froese 1992), BCCM (Froese 1996), OO (Stumpf et al. 1996), and scheduling with computer-interpretable construction method models (Fischer et al. 1996). Other information models that have been reviewed and can be found in detail in a paper from Froese (1996) are: TOPS IRM, AEC, ICON, UAM, PISA, GRM, Prim, and the AEC core model. Still more information models can be found in detail in paper from Dado et al. (1999) including: ATLAS LSE PtM, UAM, BPM, CCM, and PMICS.

The development approach also includes a review of the following developed Ontology: HiONTO (El-Diraby et al 2005), ECOGONOS (Lima et al. 2003), "Toward A Pattern Language for Discrete Event Simulation" (Changyu 2003), and OCCS (Construction Standards Institute 2003).

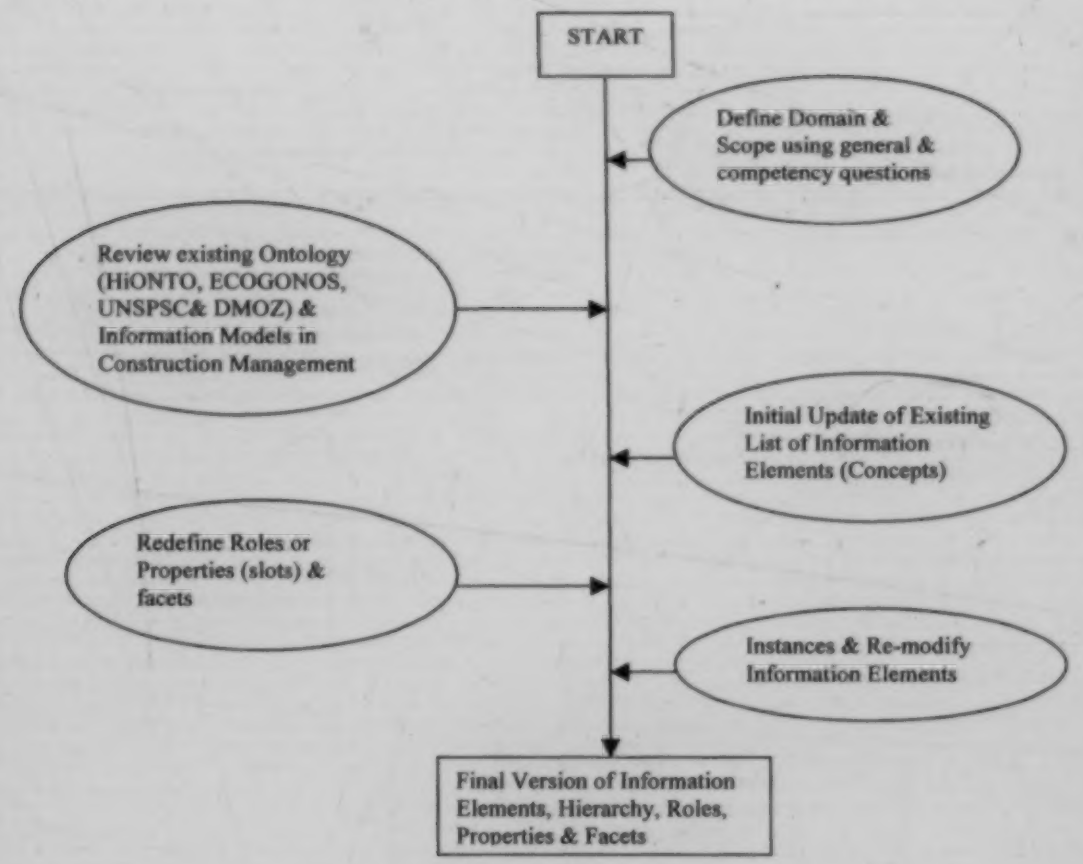

START
Define Domain & Scope using general & competency questions
Review existing Ontology (HiONTO, ECOGONOS, UNSPSC& DMOZ) & Information Models in Construction Management
Initial Update of Existing List of Information Elements (Concepts)
Redefine Roles or Properties (slots) & facets
Instances & Re-modify Information Elements
Final Version of Information Elements, Hierarchy, Roles, Properties & Facets

**Figure 3.1 : Ontology Approach**

This approach will be able to cover the limitations that exist I n developed information models so that it can be used for developing an integrated simulation system for the CM industry. Four diagrams have been designed to declare all the information elements in all four abstract levels. All related information including attributes, active roles, passive roles, and the descriptions of each element will be declared in this development.

## 3.3. APPROACH

The approach used to develop an information model for simulation in construction is based primarily on the output of the Ontology methodology described in section 3.2. Developing this information model is followed by the designing of an integrated distributed simulation system in the following paper applying the High Level Architecture (HLA) distributed simulation system. The first step was to define various abstract levels of information and end-users at each level, as shown in Figure 3.4. This was followed by defining the information element structure as shown in Figure 3.5. Finally, the information elements map is developed for every level including the information flow between these elements as described in Figures 3.6 to 3.9.

## 3.4. INTEGRATED SIMULATION - INFORMATION ARCHITECTURE

### Simulation-Information Abstract Levels

Many information models have defined the abstract levels of information structure in construction management. Some examples are the structure proposed by Sanvido et al. (1995) to link process/process and process/product through their main four attributes types (Inputs, Outputs, Mechanism, and controls). He defined the levels shown in Figure 3.2 for the product model of the facility.

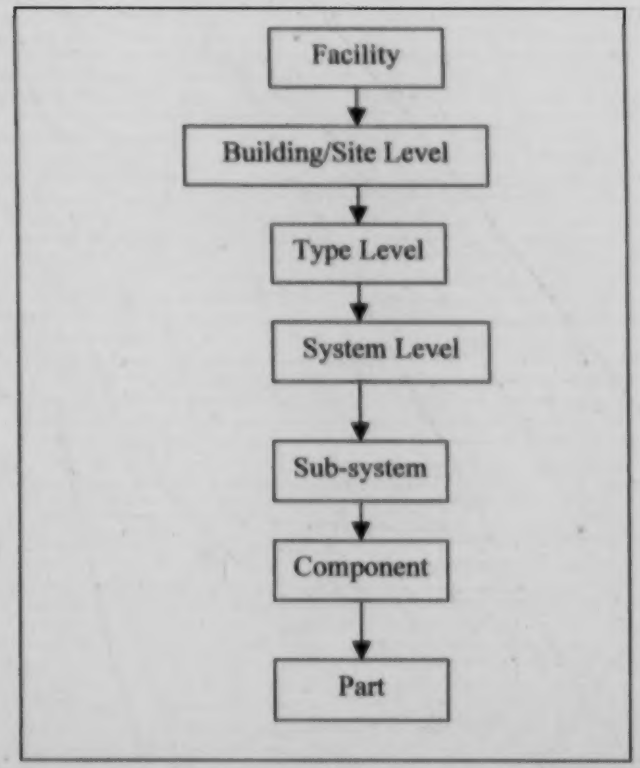



**Figure 3.2 : Information Abstract Levels proposed by Sanvido et al (1995)**

Fisher et al. (1996) defined the same breakdown for the product model excluding the type level from it. Halpin and Woodhead (1986) meanwhile, defined three levels of the process model for construction management information as shown in Figure 3.3.

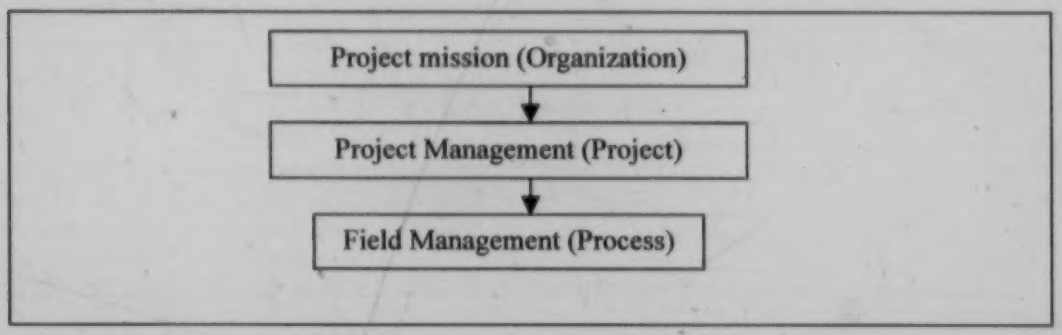



**Figure 3.3 : Information Abstract levels proposed by Halpin and Woodhead (1986)**

By comparing previous developed abstract levels and the output of comparative study of simulation and information models and systems developed for the construction industry by the authors in the previous paper, four information abstract levels are proposed to increase view-ability for construction management simulation end-users, and to facilitate information flow between simulation elements as shown in Figure 3.4.

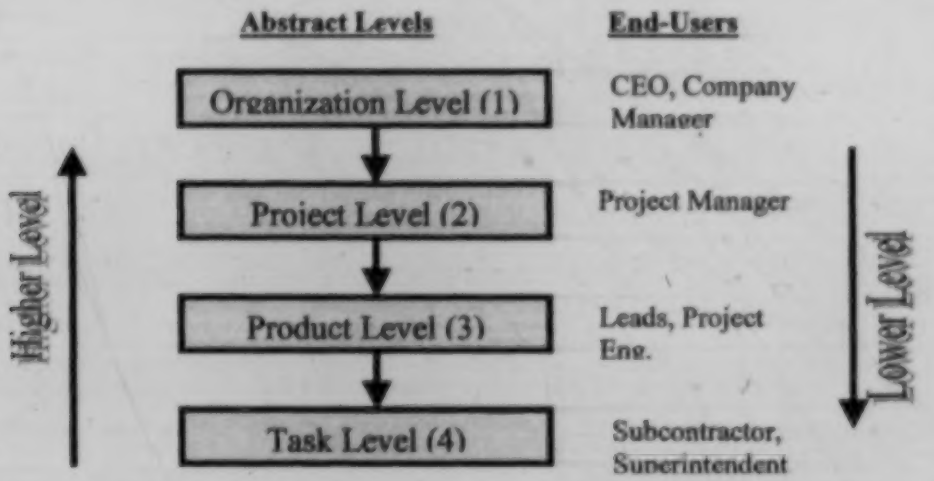



**Figure 3.4 : Information Abstract Levels and Examples of End-Users**

The next section describes the structure of simulation-information element and the output of Ontology in four information maps. This will be followed with a short section describing the needs of the simulation model to be developed and the method used to accomplish this. The details of this model will be discussed in the following paper.

**Structure of the Simulation-Information Element**

Figure 3.5 describes the proposed structure of the simulation-information element along with the type of relationship between these elements. It consists simply of information

elements names, their attributes, and a library of their passive roles. Along the relationship between two information elements are the active and/or passive roles of said elements. The active role of element X to element Y means the direction of information flow is from element X towards element Y during the simulation run. The passive role of element X towards element Z means the information flow is from element Z to element X during the simulation run.

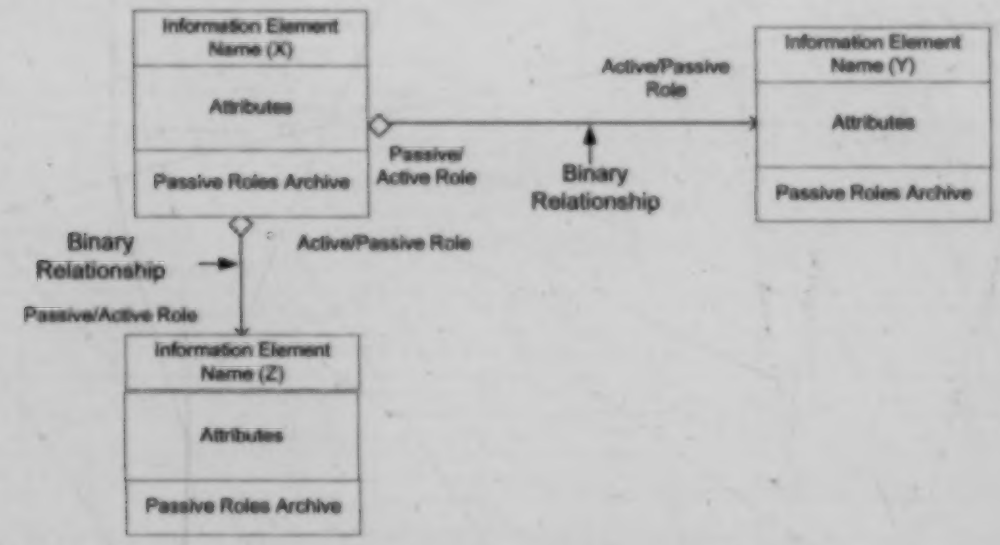



**Figure 3.5 : Simulation-Information Elements Structure**

**Simulation-Information Maps**

In this section, the output of the Ontology approach as well as the definition of the four abstract levels of construction simulation information and the previous proposed structure of the simulation information element are organized together to produce a simulation information map at every abstract level.

The first abstract level is the organization level at which simulation-information elements necessary for users are available. The user could be the Chief Executive Operator of a company or a company manager, who is interested in the highest level results of a projects simulation output only. This level is level number one and it includes 16 information elements as shown in Figure 3.6.

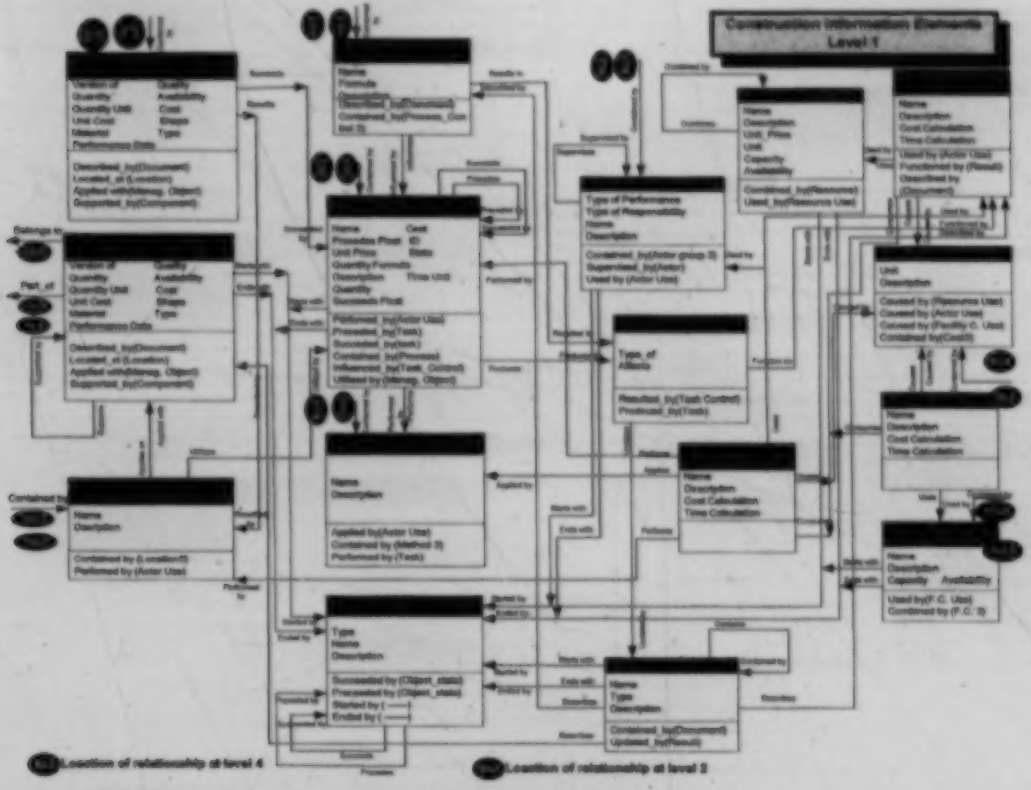



**Figure 3.6 : Simulation-Information Elements Map at Abstract Level 1 (Organization Level)**

The second abstract level is the project level at which information necessary for users is available. The user could be a project manager, who is interested only in the results of the

project simulation output. This level is level number two and it includes 17 information elements as shown in Figure 3.7.

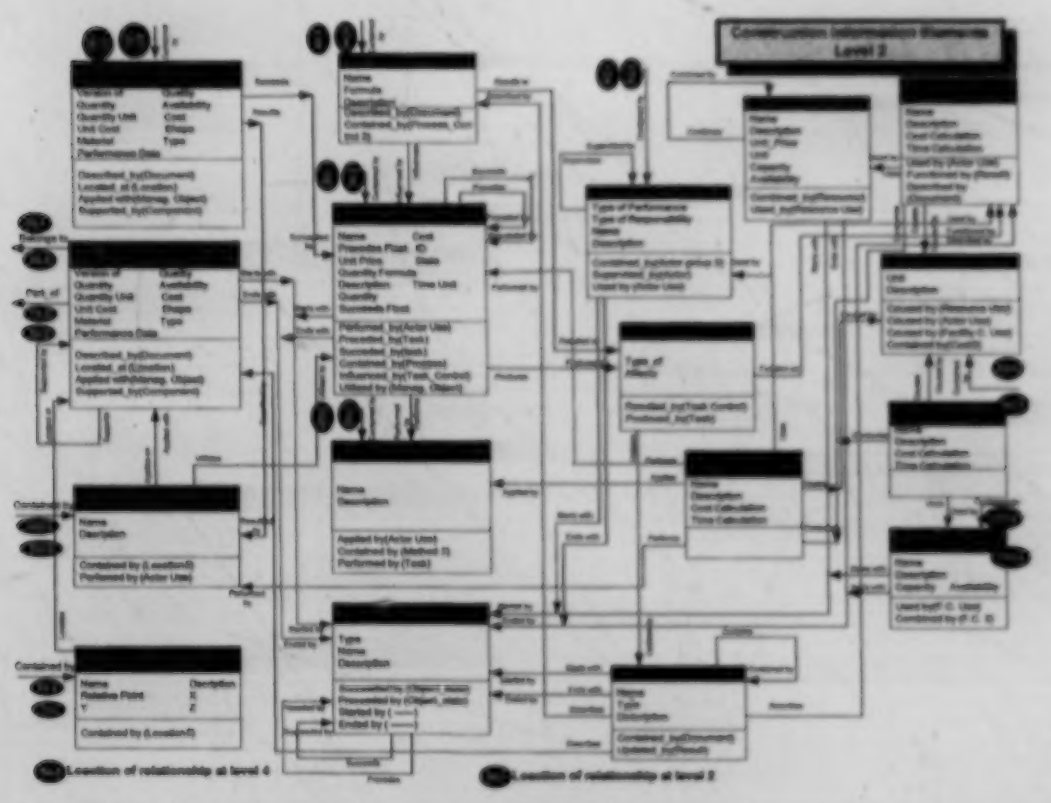


**Figure 3.7 : Simulation- Information Elements Map at Abstract Level 2 (Project Level)**

The third abstract level is the product level at which information necessary for users is available. The user could be a project engineer or technical quality lead, who is interested only in the results of the main deliverables for a project simulation output. This level is level number three and it includes 17 information elements as shown in Figure 3.8.

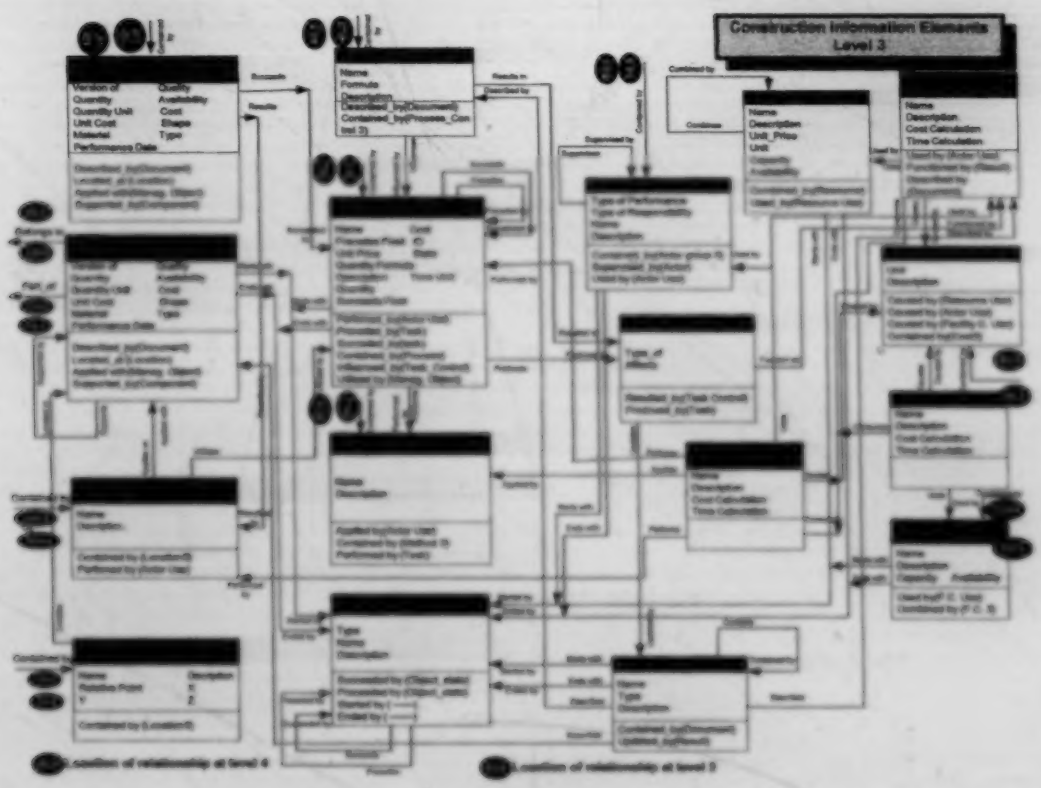



**Figure 3.8 : Simulation- Information Elements Map at Abstract Level 3 (Product Level)**

The fourth abstract level is the task level at which information necessary for users is available. The user could be a subcontractor, and/or superintendent, who are only interested in the simulation information output of the tasks required for producing the deliverables of a project. This level is level number four and it includes 13 information elements as shown in Figure 3.9.

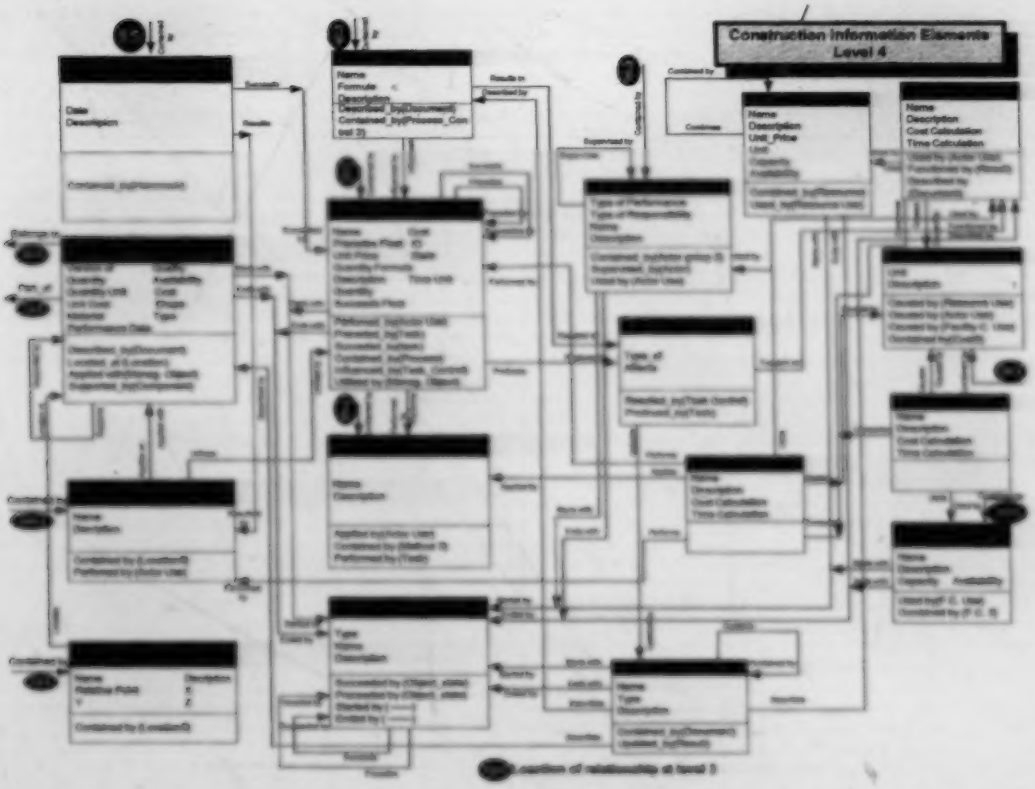



**Figure 3.9 : Simulation-Information Elements Map at Abstract Level 4 (Task Level)**

The structure of the simulation-information elements in this way, either through abstract levels or internally at each level is reflecting the information exchange form in reality and, at the same time, matching distributed simulation system process, such as High Level Architecture (HLA). HLA will be used later in another paper to create a prototype simulation model to prove the proposed approach.

The full description of the proposed simulation-information map elements at the abstract level four (Task level) is shown in Appendix 2.

## 3.5. CONCLUSION

Several conclusions can be drawn from the preliminary IICSS work presented in this chapter. It has introduced four abstract levels for information flow in the construction management simulation system. This paper presented a simulation-information model for every abstract level. The concepts of binary information flow as well as active and passive roles between the information elements were introduced. A new high-level Ontology has been defined including the information elements, and their attributes and roles. Ultimately, these information models will provide better information integration, enhance the quality of the simulation system development, and improve the current practice of distributed simulation application within construction management. The benefit of this would be to provide a flexible simulation approach, in terms of the way of working, thus enabling a convergence with the manufacturing concepts already used in the industry.

## 3.6. REFERENCES


- AbouRizk, S.M., Hajjar, D. (1998). "A framework for applying Simulation I Construction." Can. J. Civ. Eng., 25, 604-617
- Chang, D.Y., and Carr, R.I. (1987). "RESQUE: a resource oriented simulation system for multiple resource constrained processes." Proceedings of the PMI seminar/Symposium, Milwaukee, Wis., pp. 4-19.
- Changyu, Y. (2003). "Toward A Pattern Language for Discrete Event Simulation." M.Sc. University of Alberta.

- Construction Standards Institute (2003). "OCCS-Overall Construction Classification System." (www.occsnet.org)
- Cutting-Decelle, A.F., Anumba, C.J., Baldwin, A.N., Bouchlagbhem, D., Dufau, J., and Mommessin, M. (1999). "Information of Concurrent Engineering Concepts into Integrated product and process model." Concurrent Engineering in Construction Conference.
- Dado E., and Tolman F.P., 1999: " Proposal for an Integrated Information Model for Concurrent engineering of On-site Construction", International Conference for Engineering Concurrent.
- Dado, E. and Tolman, F.P. (1998). "Support of Site Construction Processes by Product Data Technology." Proceedings CIB Conference.
- Fischer, M., and Aalami, F. (1996). "Scheduling with computer-interpretable construction method models." Journal for Construction Engineering and Management, vol. 122, No. 4.
- Froese, T. M. (1992). "Integrated Computer-Aided Project Management through Standard Object-Oriented Models." Ph.D., Stanford university, June.
- Froese, T. (1996). " Models of Construction Processes Information." Journal of Computing in Civil Engineering, Vol. 10, No. 3, July, 183-193.
- Froese, T. (1998). STEP and the Building Construction Core Model." Submitted to 5th Congress On Computing On Civil Engineering, ASCE, Boston.

- Halpin, D. W. (1977). "CYCLONE: method for modeling of job site processes." ASCE Journal of the Construction Division, 103(3):489-499.
- Halpin, D. W., and Woodhead, R. W. (1976). "Design of Construction and Process Operations." Wiley, New York, 405- 413.
- Halpin, D.W., and Woodhead, R. W. (1986). "Construction Management."
- Hannus, M., Huovila, P., Lahdenpera, P., Laurikka, P., and Seren, K. (1997). "Methodologies doe Systematic Improving of Construction Processes." 1st International Conference on Computing in Structural Engineering, London.
- Huang, R., Grigoriadis, A. M., and Halpin, D.W. (1994)." Simulation of cable-stayed bridges using DISCO." Proc. Winter Simulation Conf., Inst. Of Electr. And Electronis Engrs., Piscataway, N.J., 1130-1136.
- IAI, (2002). "International Alliance for Interoperability." http://cig.bre.co.uk/iai_uk/documentation/IfcR2x_Final/index.htm.
- Ioannou, P.G. (1989). "UM-CYCLONE user's guide." Dept. of Civ. Engrg., Univ. of Michigan, Ann Arbor, Mich.
- Kamara, J. M., Anumba, C. J., Evbuomwan, N. F., and Hobbs, B. (1999). "An Information Model for Client Requirements Processing in Concurrent Life-Cycle Design and Construction." Concurrent Engineering in Construction Conference.
- Lima, C., Fies, B., El-Diraby, T.A., and Lefrancois, G. (2003). "The challenge of using a domain Ontology in KM solutions: The e-COGONOS experience." Proc., 10th ISPE Int. Conf. on Concurrent

Engineering: Research and Applications, Int Society for productivity Enhancement (ISPE) Madeira Island, Portugal. (http://isg.uninova.pt/ce2003/)

- Liu, L.Y. and Ioannou, P.G. (1992). "Graphiocal object-oriented discrete-event simulation system." Proceedings of the 1992 Winter Simulation Conference, Arlington, Va., December, pp. 1285-1291.
- Luiten, G. (1994). "Computer Aided Design for Construction in the Building Industry." Dissertation presented to Delft University of Technology.
- Luiten, G., Froese, T., Bjork, B-C, Cooper, G., Junge, R., and Oxman R. (1993). "An Information Reference Model for Architecture, engineering, and Construction." Proceedings of the first International Conference on the Management of Information Technology for Construction, Singapore, August.
- Martinez, J., and Ioannou, P.G. (1994). "General purpose simulation with stroboscope." Proceedings of 1994 Winter Simulation Conference, Atlants, Ga., pp. 1159-1166.
- McCahill, D.F. and Bernold, L.E. (1993). "Resource-oriented modeling and simulation in construction." ASCE journal of Construction Engineering and Management, 119(3): 590-606.
- Natalya, F. Noy and Deborah, L. McGuinness (2000). "Ontology Development 101: A Guide to Creating Your First Ontology." Stanford University.

- Odeh, A. M., Tommelein, I.D., and Carr, R.I. (1992). "Knowledge-based simulation of construction plans." Proceedings of the 8th Conference on Computing in Civil Engineering, ASCE, Dallas, Tex., pp. 1042-1049.
- Sanvido, Victor E., Gloria, A., Scott, B., Dan, C., Eric H., Kirby, K., Ted, L., John, M., Kevin, P., Emily, O., David, R., and Takeo, Y. (1995). "A Process based Information Architecture." Technical Report No. 36, Computer Integrated Construction Research Program, The Pennsylvania State University.
- Sawhney, A., and AbouRizk, S. M. (1995). "HSM-Simulation – Based Planning Method for Construction Projects." Journal of Construction Engineering and Management, Vol. 121, No. 3, pp. 297-303.
- Stumpf, A. L., Ganeshan, R., Chin, S., and Liu, L.Y. (1996). "Object-Oriented Model for Integrating Construction Product and Process Information." Journal of Computing in Civil Engineering, 10(3), July.

# APPENDIX 1 – GENERAL AND COMPETENCY QUESTIONS TO DEFINE SCOPE AND DOMAIN OF ONTOLOGY

The following questions have been created and answered to define the domain and the scope of the proposed ontology. The first set of questions is shown in Table 3.1 and covers the general information required to define domain and scope. Another set of questions (competency questions), designed to define the domain and scope at every abstract level of information, follows the first in Table 3.2 then Table 3.3, 3.4, and 3.5.

**Table 3-1 : General Questions**

| | |
|---|---|
| What is the domain that the ontology will cover? | Construction & Engineering Project Management (CEPM) |
| For what we are going to use the ontology? | To create flexible high level simulation elements for the applications of (CEPM) |
| For what types of questions should the information in the ontology provide answers? | What are the main product and processes information elements within CEPM?<br>What are their main roles?<br>What are their main relationships?<br>What are their main constraints? |
| Who will use and maintain the ontology? | The CEPM simulation end user & developer |
| How many hierarchy levels should I have? | Four abstract levels starting from subcontractor to the CE company owner |
| How does it mean abstract level? | It is direction of information flow in CEPM industry from top management level to the lowest management level. It is simply WBS of management with tasks appear at all levels and not only the lowest level. |
| Which existing Ontology could be used? | HiONTO, ECOGONOS, UNSPSC& DMOZ |
| Is there any other existing information models that can be used? | IFC 2X, UniClass, OCCS & other information models (COMBINE, ICON, OSCON, SPACE, COMMIT, ToCEE, and WISPER) |
| Which processes should be utilized here? | All processes within CEPM as defined in PMBOK; that includes around 39 processes. |
| Which products should be utilized here? | They are the outputs of the processes in PMBOK. |
| Which previous definition can be used to | Halpin and Woodheadm (1976) |

| | |
|---|---|
| create and define the abstract levels? | Halpin and Woodhead (1986)<br>Fisher et al. (1996)<br>Sanvido et al. (1995) |
| How many abstract levels should be described? | Four abstract levels starting from Organization level at the highest level to project, process, and task level at the lowest level. |

**Table 3-2 : Competency Questions at Level 4**

| | |
|---|---|
| Who is the end-user of this information at this abstract level? | Examples are: Subcontractor – Superintendent – Site Engineer |
| What type of information elements should be involved here? | All elements (concepts) that exchange data directly or indirectly from/to task element. The task element is the lowest level in the WBS. Detailed list is shown in Appendix 2. |
| What are the tools that are used to define these elements? | Previous Ontology such as HiONTO, ECOGONOS and Yin's user construction model elements. Also all state-of-the-art in information model; including: IFC2X Edition 2 and PMBOK (and it extended edition for construction management). Finally, all Academic and Industrial references. |
| Which attributes should each element have? | All characteristics that can differentiate one instance from another for the same element. A detailed list is shown in Appendix 2. |
| What are the types of values for these attributes? | It will be simple numeric, complex numeric, text, or enumerated values. Detailed list is shown in Appendix 2. |
| What are the roles of each element to other elements at the same level? | The roles will be either active or passive roles (slot). Active means that this element is transferring this data to another related element. Passive means that this element is receiving this data from another related element. A detailed list is shown in Appendix 2. |
| What are the roles of each element to other elements at the higher level? | The roles are mainly type of Parent-Children relations. The Parent is collecting data from children and analysing it. |
| What is the information transfer through each role between these elements? | It is the new value of some attributes after each simulation run. A detailed list is shown in Appendix 2. |
| What are the output values that should be measured and analysed for each element at the end of simulation? | It is either the updated values of the attributes for all construction & engineering management deliverables or products. A detailed list is shown in Appendix 2. |
| How are product and process elements integrated here? | Using the state of art in information models and IFC2X Edition 2. |

**Table 3-3 : Competency Questions at Level 3**

| | |
|---|---|
| Who is the end-user of this information at this abstract level? | Examples are : Site Manager – Junior Quality Engineer – Junior Scheduler – Junior Project Control Specialist |
| What type of information elements should be involved here? | All elements (concepts) that exchange data from or to process element. The process element is a group of tasks that share some main characteristics. |
| What are the tools that be used to define these elements? | Previous Ontology such as HiONTO, ECOGONOS and Yin's user construction model elements. Also all state-of-art in information model including IFC2X Edition 2. PMBOK and it extended edition for construction management. Finally, all Academic and Industrial references. |
| Which attributes should each element have? | All characteristics that can differentiate one instance from another one for the same element. |
| What are the types of values for these attributes? | It will be simple numeric, complex numeric, text or enumerated values. |
| What are the roles of each element to other elements at the same level? | The roles will be either active or passive roles (slot). The active means that this element is transferring this data using this role to another related element. The passive means that this element is receiving this data using this role from another related element. |
| What are the roles of each element to other elements at the higher level? | The roles are mainly type of Parent-Children relations. The Parent is collecting data from children and analyses it. |
| What is the information transfer through each role between these elements? | It is the new value of some attributes after each simulation run. |
| What are the output values that should be measured and analysed for each element at the end of simulation? | It is either the updated values of the attributes for all construction and engineering management deliverables or products. |
| How are product and process elements integrated here? | Using the state of art in information models and IFC2X Edition 2. |

**Table 3-4 : Competency Questions at Level 2**

| | |
|---|---|
| Who is the end-user of this information at this abstract level? | Examples are : Project Manager – Senior Quality Engineer – Senior Scheduler – Senior Project Control Specialist |
| What type of information elements should be involved here? | All elements (concepts) that exchange data from or to project element. The project element is a unique entity that has defined objectives, start, end and temporary status. |
| What are the tools that be used to define these elements? | Previous Ontology such as HiONTO, ECOGONOS and Yin's user construction model elements. Also all state-of-art in information model including IFC2X Edition 2. PMBOK and it extended edition for construction management. Finally, all Academic and Industrial references. |
| Which attributes should each element have? | All characteristics that can differentiate one instance from another one for the same element. |
| What are the types of values for these attributes? | It will be simple numeric, complex numeric, text or enumerated values. |
| What are the roles of each element to other elements at the same level? | The roles will be either active or passive roles (slot). The active means that this element is transferring this data using this role to another related element. The passive means that this element is receiving this data using this role from another related element. Detailed list is shown in Appendix 1. |
| What are the roles of each element to other elements at the higher level? | The roles are mainly type of Parent-Children relations. The Parent is collecting data from children and analyses it. |
| What is the information transfer through each role between these elements? | It is the new value of some attributes after each simulation run. |
| What are the output values that should be measured and analysed for each element at the end of simulation? | It is either the updated values of the attributes for all construction and engineering management deliverables or products. |
| How are product and process elements integrated here? | Using the state of art in information models and IFC2X Edition 2. |

**Table 3-5 : Competency Questions at Level 1**

| | |
|---|---|
| Who is the end-user of this information at this abstract level? | Examples are : Senior Project Manager – CEO – Project Controls Lead – Functional Lead |
| What type of information elements should be involved here? | All elements (concepts) that exchange data from/to organization element. The project element is a unique entity that has defined objectives, start, end and temporary status. Detailed list is shown in Appendix 1. |
| What are the tools that be used to define these elements? | Previous Ontology such as HiONTO, ECOGONOS and Yin's user construction model elements. Also all state-of-art in information model including IFC2X Edition 2. PMBOK and it extended edition for construction management. Finally, all Academic and Industrial references. |
| Which attributes should each element have? | All characteristics that can differentiate one instance from another one for the same element. |
| What are the types of values for these attributes? | It will be simple numeric, complex numeric, text or enumerated values. |
| What are the roles of each element to other elements at the same level? | The roles will be either active or passive roles (slot). The active means that this element is transferring this data using this role to another related element. The passive means that this element is receiving this data using this role from another related element. |
| What are the roles of each element to other elements at the higher level? | The roles are mainly type of Parent-Children relations. The Parent is collecting data from children and analyses it. |
| What is the information transfer through each role between these elements? | It is the new value of some attributes after each simulation run. |
| What are the output values that should be measured and analysed for each element at the end of simulation? | It is either the updated values of the attributes for all construction and engineering management deliverables or products. |
| How are product and process elements integrated here? | Using the state of art in information models and IFC2X Edition 2. |

# APPENDIX 2 – CONSTRUCTION INFORMATION ELEMENTS DESCRIPTION AT ABSTRACT LEVEL 4

**Element (1) : Component**

**Definition** Physical element of construction project that forms with other components the final product of the project.

**Active Roles**

Part of (Product at higher level)

Supports (Other Component)

Belongs to (Construction Zone at higher level)

Starts with (Object State)

Ends with (Object State)

Contains (parts)

**Passive Roles**

Described by (Document)

Applied with (Management Object)

Supported by (Component)

Locates_at (Location) (X,Y,Z coordinates)

**Attribute**

| | | |
|---|---|---|
| Version of | Quantity | Quantity unit |
| Unit Cost | | |
| quality | availability | cost |
| Shape | material | performance data |

Type (required, planned or managed)

**Type of Relationships**

(C) Product

(C) Other Component

(CI) Construction Zone

(CI) Object State

(C) Parts

---

**Element (2) : Actor**

**Definition** The human resources which perform a task and play a role in construction project.

**Active Roles**

Starts with (Object State)

Ends with (Object State)

Supervises (Actor)

**Passive Roles**

Contained by (Actor Group at higher level)

Supervised by (Actor at same level or higher level)

Used by (Actor Use)

**Attribute**

Type of Performance (Estimate, Supervise, Handle, Records, Coordinate, Quantity Estimate, Report, Progress Photograph, Inspect, Purchase, Coordinate, Survey, Implement, Monitor, Quality Control, Review (constructability, bid-ability, operability, submittals, materials, shop drawings and contractor's progress).

Type of Responsibility (as in PSI scope matrix)

Name

Description

**Type of Relationships**

(C) Method

(C) or (CI) Task ..... User can decide that according to his

case

(CI) Resource

(CI) Object State

(C) Actor

---

**Element (3) : Task**

**Definition** : The construction effort performed by actor to produce result.

**Active Roles**

Succeeds (Task)

Precedes (Task)

Produces (Result)

Performs_on (Part)

Starts with (Object State)

Ends with (Object State)

Performs (Method)

**Passive Roles**

Performed by (Actor Use)

Succeeded by (Task)

Preceded by (Task)

Contained by (Process at higher level 3)

Influenced by(Task Control)

Utilized by (Management Object)

**Attribute**

| | | |
|---|---|---|
| Name | Description | Succeeds float |
| Precedes float | Quantity | Quantity Formula |
| Time Unit | State | ID |

**Type of Relationships**

(C) Task

(CI) Result

(C) Part

(CI) Object State

(C) Method

---

**Element (4) : Task Control**

**Definition** Things constrain task to be executed according to plan such as change order, schedules, contracts conditions, weather condition…etc.

**Active Roles**

Influences (Task at the same level)

Results in (Result at the same level)

**Passive Roles**

Described by (Document)

Contained by (Process Control at higher level)

**Attribute**

Name

Description

Formula (Rules)

**Type of Relationships**

(C) Task

(C) Result

N.B.: Rules can be used to express them as in Yasser's thesis.

---

**Element (5) : Result**

**Definition** : Is the output of performing one of the tasks.

**Active Roles**

Function as (Resource)

Updates (Document)

**Passive Roles**

Produced by (Task)

Resulted by (Task Control)

**Attribute**

Type of (Control (Information)(such as in drawings, contracts, paper or electronic documents), Product (Physical)(components put into place), and Resource (Service) (such as temporary work))

Affects (another element)

**Type of Relationships**

(C) Resource

(C) Document

---

**Element (6) : Document**

**Definition** : An original or official paper, drawing, or electronic file relied on as the basis, proof, or support of something in construction process.

**Active Roles**

Describes (component if it is drawing or specification, or resource if it is purchase order)

Describes (Task Control)

Describes (Resource Use)

Contains (another document)

Starts with (Object State)

Ends with (Object State)

**Passive Roles**

Updated by (Result)

Contained by (Document)

**Attribute**

| Name | Type | Description |
|---|---|---|

**Type of Relationships**

(C) Component

(C) Document

(CI) Object State

**Element (7) : Resource**

**Definition** : It is anything, other than human resources or facility (infrastructure), that is required by any task to be performed.

**Active Roles**

Starts with (Object State)

Ends with (Object State)

Combines (Resource)

**Passive Roles**

Combined by (another resource)

Used by (Resource Use)

**Attribute**

Name

Description

Unit price

Unit(for measuring as meters)

Capacity (Quantity)

Availability

**Type of Relationships**

(C) Resource Use

(CI) Object State

(C) Resource

---

**Element (8) : Object State**

**Definition** : Is the value for set of variables describing specified object (part, component, resource, actor, document or task) in construction project at specified time.

**Active Roles**

Succeeds (another object state)

Precedes (another object state)

**Passive Roles**

Succeed by (another object state)

Preceded by (another object state)

Started_by(Resource)

Ended_by(Resource)

Started_by(Actor)

Ended_by(Actor)

Started_by(Task)

Ended_by(Task)

Started_by(Document)

Ended_by(Document)

Started_by(Part)

Ended_by(Part)

Started_by(Component)

Ended_by(Component)

Started_by(Facility Component)

Ended_by(Facility Component)

**Attribute**

Type (part, component, resource, actor, document or task)

Name (it will be drop list box shown automatically according to type selected in first step, e.g. if it is part or component it will be as required or as designed or as built. And if it is task, it could be pre-request, or result.

Description

**Type of Relationships**

(I) Object State

**Element (9) : Resource Use**

**Definition** : It represents the use of a specific resource for a specific construction task or activity. (With using resource use, it is possible to use one resource at several activities and deal with every use separately )

**Active Roles**

Causes (Cost)

Uses (Resource)

Consumes (Time)

**Passive Roles**

Used by (Actor Use)

Functioned by (Result)

Described (Document)

**Attribute**

Name

Description

Cost Calculation

Time Calculation

**Type of Relationships**

(I) Cost

---

**Element (10) : Method**

**Definition** : Is a particular construction technique or technology used to perform a task to achieve its planned objectives.

**Active Roles**

Performs on (Part)

**Passive Roles**

Contained by (Method 3 at higher level)

Applied by (Actor Use)

Performed by (Task)

**Attribute**

Description:

**Type of Relationships**

(C) Task

(I) Task Control

---

**Element (11) : Location**

**Definition** : Is the X,Y and Z position of any component relative to specified point in the construction site.

**Active Roles**

Locates (Component)

**Passive Roles**

Contained by (Location 3)

**Attribute**

Name:

Description:

Relative Point:

X:

Y:

Z:

**Type of Relationships**

(CI) Component

**Element (12) : Cost**

**Definition** : Is the money value of applying any resource, actor, or facility component to any task.

**Active Roles**

**Passive Roles**

Caused by (Resource Use)

Contained by (Cost 3)

Caused by (Actor Use)

Caused by (Facility Use)

**Attribute**

Unit

Description

**Type of Relationships**

**Element (13) : Milestone**

**Definition** : It is specified date that should be met during construction project life cycle.

**Active Rome**

Succeeds (Task)

Results (Management Object)

**Passive Roles**

Contained by (Hammock at level 3)

**Attributes**

Date

Description

**Type of Relationships**

N/A

---

**Element (14) : Management Object**

**Definition** : Is the smallest component of any project management tool that may use to help decision makers achieving the planned goals.

**Active Roles**

Utilizes (task)

Applies on (Component)

**Passive Roles (Protons):**

Contained by (Management System at level 3)

Performed by (Actor Use)

**Attributes**:

Description (drop list menu such as plan, schedule, cost control, cost estimate, quality control…….)

**Type of Relationships**

(C) Task

(C)Component

**Element (15) : Actor Use**

**Definition** : It represents the use of a specific actor for a specific task or activity. (With using actor use, it is possible to use one actor at several activities and deal with every use separately)

**Active Roles**

Causes (Cost)

Performs (Object Management)

Consumes (Time)

Applies (Method)

Performs (Task)

Uses (Resource Use)

Uses (Actor)

**Passive Roles**

**Attribute**

Name

Description

Cost Calculation

Time Calculation

**Type of Relationships**

(I) Cost

(C) Object Management

(C) Time

---

**Element (16) : Facility Component**

**Definition** : It is anything, other than actor or resource, that is required by any task to be performed.

**Active Roles**

Starts with (Object State)

Ends with (Object State)

**Passive Roles**

Contained by (Facility Component 3 at higher level)

Used by ( Facility Component Use)

**Attribute**

Name

Description

Capacity (Quantity)

Availability

**Type of Relationships**

(CI) Object State

---

**Element (17) : Facility Component Use**

**Definition** : It represents the use of a specific facility component for a specific task or activity. (With using actor use, it is possible to use one facility component at several activities and deal with every use separately)

**Active Roles**

Causes (Cost)

Uses (Facility Component)

Consumes (Time)

**Passive Roles**

**Attribute**

Name

Description

Cost Calculation

**Type of Relationships**

(I) Cost

(C) Time

(C) Facility Component

---

# CHAPTER 4. INTEGRATED DISTRIBUTED SIMULATION SYSTEM FOR CONSTRUCTION MANAGEMENT

## 4.1. ABSTRACT

Although construction management simulation has been successful in academic research with a large number of developed languages and systems, it has not been accepted into the construction management industry to any significant degree. The development of simulation models is not only time-consuming, requiring programming and simulation background, but it also does not express the reality of construction management processes and their outputs. Previous researchers in this field always tried to build their simulation languages or systems by concentrating more on execution simulation and not operational simulation. Simulation engine is taking care of execution, while operational simulation is the interface between simulation developer / end-user and this engine. This research is trying to drive construction management simulation research towards reality, using the information models developed in the previous paper. This step is followed by developing a conceptual design for a new automated pattern for simulation using similarities with chemical theories and principles in following paper. The research is an endeavor to increase the acceptance of simulation in the construction industry, simplify its operational phase, and minimize the simulation knowledge needed by end-users.

## 4.2. INTRODUCTION

Since the first trial of Halpin (1976) to create and design a construction simulation language (CYCLONE), many subsequent research works have been developed towards achieving the same objective, including RESQUE (Chang 1986), Um-CYCLONE (Ioannou 1989), COOPS (Liu and Ioannou 1992), DISCO (Huang et al. 1994), and CIPROS (Tommelein et al. 1994). McCabe and AbouRizk (2001) described in detail many of these approaches and languages.

In order to increase the acceptance of simulation in the construction industry, this paper attempts to investigate an alternative construction simulation approach from an information-oriented perspective. This approach focuses mainly on the type of information elements and the pattern of their interactions. This includes data transferred between these elements during the simulation run, as well as the hierarchy of the elements for various end-users. To achieve this goal, a distributed simulation technology will be used. The High Level Architecture (HLA) system developed by the department of defence in the United States is applied for that. The term "distributed simulation" refers to distributing the execution of a single run of a simulation program across multiple processors (Fujimoto 2003). The main reason behind developing this system is to increase the available memory for the simulation execution and integration of different simulation subsystem. HLA could be used also to increase the opportunity for different end-users of construction industry to track and view results of the simulation model from their individual perspectives. HLA will be applied here to achieve this goal.

Each company in the construction industry ends with building their own customized software for management purposes. The cost of the development and maintenance of simulation models that suit this software will be very high. Even a simulation model that is built for one system or project is of little or no use to another one. Also, the model is designed to track only one process of construction management, such as scheduling control, cost control, time control, resources control, or others. No system is standardized to track these processes together. With the available simulation systems, most creative responsibility is left to the simulation analyst, who could not be knowledgeable enough to reflect reality in the developed model. This increases the needs to design a standardized information transaction pattern for simulation systems. Mclean et al. (2003) mentioned that one of standardization methods could be the standardization of simulation components or elements. Schultz et al. (2002) introduced one of these trials of standardization for the graphical interface of simulation. This paper describes the building of information-based simulation elements and their attributes and relationships using the distributed simulation system to increase accessibility and reliability of simulation models for various end-users. The aim of applying distributed simulation system is to facilitate this accessibility, and not to distribute simulation among different processors. The following paper describes an automated approach of the elements interactions and their standardized outputs. The HLA system that will be used here is called *Simphony* 2.0 that was developed by the Hole School of Construction Engineering at the University of Alberta in 2005. The system consists of three main components: the Object Modeling Template (OMT) Editor using XML, the Run Time Infrastructure (RTI), and the environment to design and create the main components of HLA, including

Federation and their Federates. This environment uses Microsoft Visual Basic.Net. The paper introduces the design of the Federate Object Model (FOM), the mapping matrix of IICSS elements, sample interfaces in the HLA environment, algorithms of the main federates at the abstract level 4, and a prototype of this model in *Simphony* and Excel sheet. The different construction management areas represent parent elements inside the simulation environment.

## 4.3. HIGH LEVEL ARCHITECTURE BACKGROUND

Distributed simulation technology has started in the late 1970's. The defense department started its work in distributed simulation systems with SIMNET (SIMulator NET working) project. The project aimed to create virtual training environments. This lead to the development of the Distributed Interactive Simulation (DIS) standards. The next development step was HLA in the 1990's. It is intended to promote the reuse and interoperation of simulations (Fujimoto 2003). HLA consists of Federations that represent HLA-based distributed simulation elements. Each Federation consists of a collection of interacting simulations, termed Federates. The manager of data exchange between these Federates is the Run Time Infrastructure (RTI) software. HLA is defined by the HLA rules, Object Model Template (OMT), and interface specification. The HLA rules are either Federate or Federation rules. Ownership of the attributes of any instance of any object is recognized by only one Federate at any specified time. It is called the Federate Object Model (FOM) when describing and organizing Federation information, and the Simulation Object Model (SOM) when describing and organizing future Federation information. OMT is a standard way for documenting HLA object model

information. It consists of many tables that specify information about the classes of objects, their attributes, and their interactions. It includes the following tables:

- Object Model Identification Table
- Object Class Structure Table
- Interaction Class Structure Table
- Attribute Class Structure Table
- Parameters Table
- Routing Space Table

The interface specifications define the functional interfaces between the Federates and the RTI, and how the Federates will interact with one another. It consists of six main management areas:

- Federation Management
- Declaration Management
- Object Management
- Ownership Management
- Data Distribution Management
- Time Management

The transfer of data inside the HLA environment has an implicit-invocation style (Kuhl et al. 1999). The Federate declares either its intent to produce (publish), consume (subscribe to), or produce/consume data. The declaration management services control this within each Federation.

## 4.4. DISTRIBUTED INFORMATION-BASED SIMULATION SYSTEM IMPLEMENTATION

Time management refers to synchronizing the execution of the simulation. It is assumed that each Federate is a single logical process (LP) (Schulz et al. 2002) that communicates with others by exchanging time-stamped messages or events. The simulation engine could be time-stepped or discrete-event. For our prototype design, the time-stepped engine is applied. The data that is transferred during the simulation run is called the interaction, while data transferred for the second action is called the object (Boer et al. 2003). Interactions carry a set of parameters, while objects carry a set of attributes. To prove this methodology, a prototype system was developed. The primary aim of the prototype development and case applications was to prove the feasibility of developing a distributed simulation system while adopting information-oriented simulation concepts. There are three main significant consecutive steps to develop this system. The first step is to map information model to the HLA components, and the second is to design the suitable LP algorithm for each Federate and the process of their interrelationships using time-stepped simulation. The third step is to verify the correct logical steps of these algorithms by prototyping these algorithm in an Excel sheet, as shown in Figure 4.1.

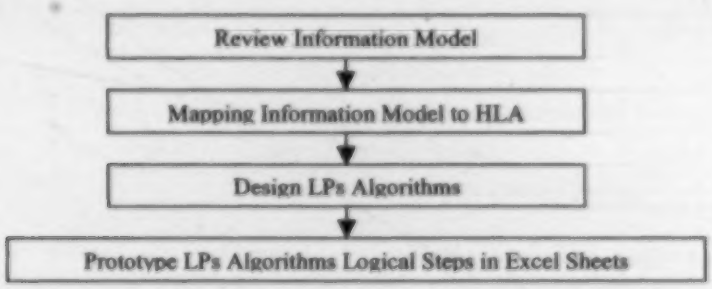

Review Information Model
Mapping Information Model to HLA
Design LPs Algorithms
Prototype LPs Algorithms Logical Steps in Excel Sheets

**Figure 4.1 : Flow Chart of Prototype Development**

**Mapping IICSS Objects to the HLA Environment**

The internal design of a system under the HLA environment will be based on the Federation that represents the system. The Federation consists of several Federates, and each Federate represents one construction management process as shown in Figure 4.2. Abstract level four IICSS4 Federation (the lowest level in information transformation) consists of the following Federates: the schedule control Federate, cost control Federate, cost estimate Federate, time control Federate, resources control Federate, document control Federate, quality control Federate, and the risk management Federate. A description of each Federate is illustrated in appendix 3. Table 4.1 illustrates a table used to map the proposed information model elements to objects in HLA for IICSS4 and the responsibility of each Federate towards their attributes in terms of the data publish /subscribe declaration. The table represents each information element as an object. Each Federate is either Publish (P), Subscribe(S), Publish/Subscribe (P/S), or has no desire to exchange data of these attributes. These IICSS objects and their attributes are mapped to the FOM in the OMT editor of Simphony 2.0 as shown in Figure 4.3.

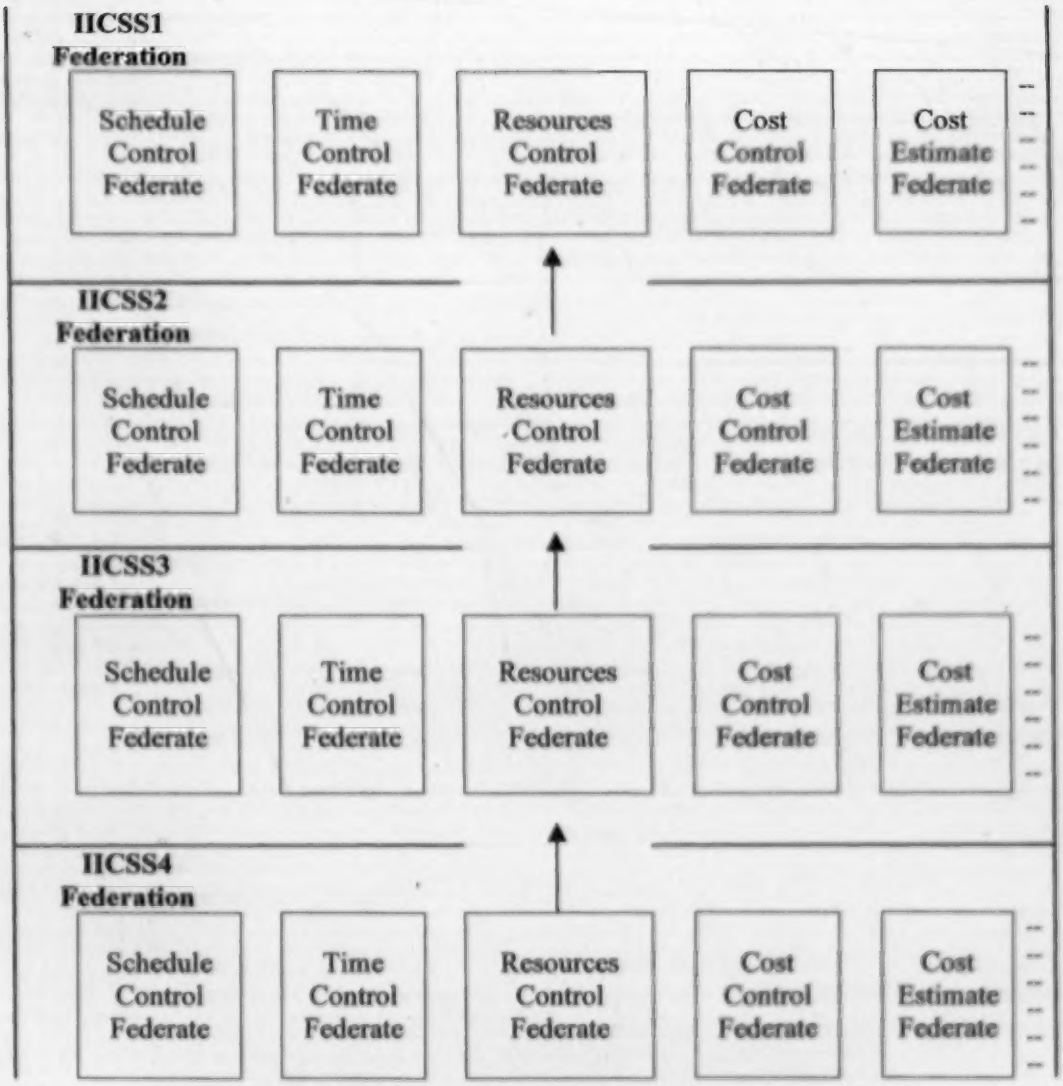



**Figure 4.2 : Structure of IICSS in HLA Environment**

**Table 4-1 : Matrix of IICSS Elements Mapping to HLA Objects**

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| **Component** | ID | S | S | S | S | | | | | P/S |
| | Name | | | | P | | | | | |
| | Version # | P | | | | | | | | P/S |
| | Original Quantity | S | S | | | | P | | | S |
| | Quantity unit | P | S | | | | | | | S |
| | Quality Limit | P | S | | | | | | | S |
| | Availability (available, not available) | P | | | S | | | | | |
| | Unit Cost ($/Unit) | S | S | | | | P | | | |
| | Cost ($) | S | S | | | | P | | | |
| | Shape | | | P | | | | | | S |
| | Material | | | P | | | | | | S |
| | % Physical Complete | | S | P | | | | | | |
| | Planned Start (Calendar Time) | S | | | P | | | | | |
| | Planned Finish (Calendar Time) | S | | | P | | | | | |
| | Control/Inspection Result | | | | | | | | | |
| | CWBSCode | S | S | S | P | | S | | | |
| **Actor** | Type of Performance (Estimate, Supervise, Handle, Records, Coordinate,Quantity Estimate, Report, Progress_Photograph, Inspect, Purchase,Coordinate, Survey, Implement, Monitor, Quality Control, Review (constructability, ildability, operability, submittals, materials, shop drawings and contractor's progress). | P | | | | | | | | |

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | ID | S | | | P | | | | | |
| | Type of Responsibility (responsible, not responsible, share) | S | | • | | | | | | |
| | Name | S | | | | | | | | |
| | ATD ($) | P | | | | | | | | |
| | ATD (hr.) | P | | | | | | | | |
| | Start (Calendar Time) | S | | | P | | | | | |
| | Finish (Calendar Time) | S | | | P | | | | | |
| | Unit Rate ($/hr) | P | | | S | | | | | |
| **Task** | Name | S | | | P | | | | | |
| | Description | S | | | P | | | | | |
| | Duration (Day) | S | | | P | | | | | |
| | Planned Start (Calendar Time) | S | | | P | | | | | |
| | Planned Finish (Calendar Time) | S | | | P | | | | | |
| | Forecast Start (Calendar Time) | S | | | P | | | | | |
| | Forecast Finish (Calendar Time) | S | | | P | | | | | |
| | ID | S | | | P | | | | | |
| | Status (Completed, Under Progress, Not Started, Delayed) | S | | | P | | | | | |
| | PV | P | | S | | | | | | |
| | SPI | P | | S | | | | | | |
| | Original Budget (hr) | S | | S | | | P | | | |
| | Trends ($) | P | S | | | | | | | |
| | BudgetShift($) | P | S | | | | | | | |
| | ChangeOrder($) | P | S | | | | | | | |
| | Original Budget ($) | P | S | | | | | | | |
| | ETC Trends ($) | P | S | | | | | | | |
| | ETC BudgetShift($) | P | S | | | | | | | |
| | ETC ChangeOrder($) | P | S | | | | | | | |

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | Trends (hr) | P | | S | | | | | | |
| | BudgetShift(hr) | P | | S | | | | | | |
| | ChangeOrder(hr) | P | | S | | | | | | |
| | ETC Trends (hr) | P | | S | | | | | | |
| | ETC BudgetShift(hr) | P | | S | | | | | | |
| | ETC ChangeOrder(hr) | P | | S | | | | | | |
| | CurrentBudget($) | P | S | | | | | | | |
| | CurrentBudget(hr) | P | | S | | | | | | |
| | EAC ($) | S | P | | | | | | | |
| | EAC (hr) | S | | P | | | | | | |
| | EV($) | S | P | | | | | | | |
| | EV(hr) | S | | P | | | | | | |
| | CPI | S | P | | | | | | | |
| | HPI | S | | P | | | | | | |
| | %Duration Complete | S | | | P | | | | | |
| | WBSCode | S | | | P | | | | | |
| **Milestone** | ID | S | | | P | | | | | |
| | Name | S | | | P | | | | | |
| | Description | S | | | P | | | | | |
| | Status (Complete, Under Progress, Delayed) | S | | | P | | | | | |
| | Forecast Start (Calendar Time) | S | | | P | | | | | |
| | Planned Start (Calendar Time) | S | | | P | | | | | |
| **Result** | Type of (Control (Information(such as in drawings, contracts, paper or electronic documents), Product (Physical) (components put into place), ), and Resource (Service) (such as temporary work)) | P | | | | | | | | S |

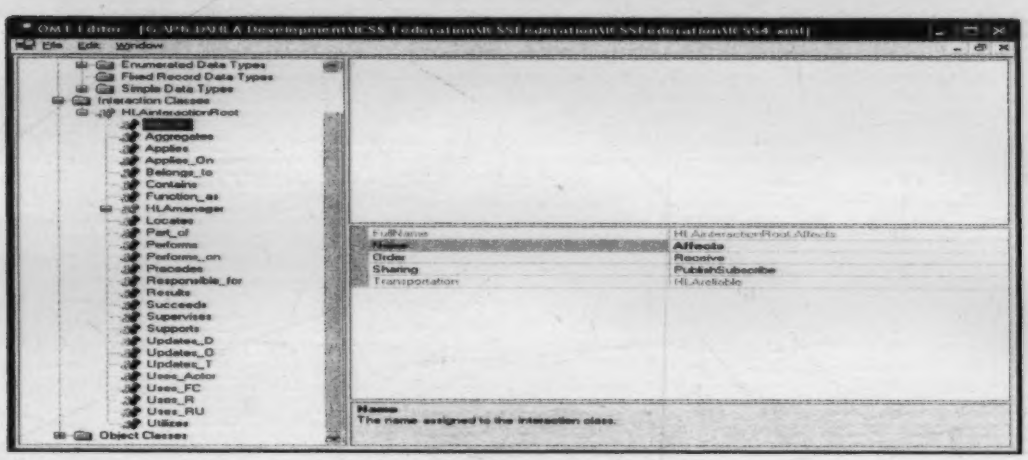
| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | Planned Available Time (Calendar time) | S | | | P/S | | | | | |
| | Forecast Available Time (Calendar time) | S | | | P/S | | | | | |
| | ID | P | | | | | | | | S |
| **Document** | Name | S | | | | | | | | P |
| | Type | S | | | | | | | | P |
| | Description | S | | | | | | | | P |
| | ID | S | | | | | | | | P |
| | DocumentReferences | S | | | | | | | | P |
| | Purpose | S | | | | | | | | P |
| | Scope | S | | | | | | | | P |
| | Revision | P | | | | | | | | S |
| | DocumentOwner | S | | | | | | | | P |
| | Editors | S | | | | | | | | P |
| | CreationTime (Calendar Time) | S | | | | | | | | P |
| | LastRevisionTime (Calendar Time) | S | | | | | | | | P |
| | ElectronicFormat | P | | | | | | | | S |
| | ValidFrom | S | | | | | | | | P |
| | ValidUntil | S | | | | | | | | P |
| | Status | S | | | | | | | | P |
| **Resource** | Name | P | | | | | S | | | |
| | ID | P | | | | | S | | | |
| | Description | P | | | | | S | | | |
| | Unit price ($/unit e.g $/hr)) | P | | | | | S | | | |
| | Unit(for measuring e.g. meters) | P | | | | | S | | | |
| | Capacity (Quantity (Units)) | P | | | | | S | | | |
| | ATD ($) | P | | | | | | | | |
| | ATD (hr.) | P | | | | | | | | |

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | Availability (available, not available) | P | | | S | | | | | |
| | Available Quantity (Quantity (Units)) | | | | | | | | | |
| | ResourceConsumption (Enumeration of consumed, partially consumed, not consumed. Occupied, partially occupied, not occupied, user defined, not defined) | P | S | S | S | | | | | |
| **Resource Use** | Name | P | S | S | S | | | | | |
| | Description | P | S | S | S | | | | | |
| | ID | P | S | S | S | | | | | |
| | Usage | P | | | | | | | | |
| | % Usage | P | | | | | | | | |
| | OB ($) | | | | S | S | P | | | |
| | OB (hr.) | | | | S | S | P | | | |
| | CB ($) | | | | S | P | | | | |
| | CB (hr.) | | | | S | P | | | | |
| | ATD ($) | | S | | | | P | | | |
| | ATD (hr.) | P | | | S | | P | | | |
| **Location** | Name | P | | | | | | | | S |
| | Description | P | | | | | | | | S |
| | Relative Point:X: Y: Z | P | | | | | | | | S |
| | GlobalId | P | | | | | | | | S |
| **Actor Use** | Name | P | S | S | S | | | | | |
| | ID | P | S | S | S | | | | | |
| | Description | P | S | S | S | | | | | |
| | Usage | P | | | | | | | | |
| | % Usage | P | | | | | | | | |
| | OB ($) | | | | S | S | P | | | |

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | OB (hr.) | | | | S | S | P | | | |
| | CB ($) | | | | S | P | | | | |
| | CB (hr.) | | | | S | P | | | | |
| | ATD ($) | P | | | S | | P | | | |
| | ATD (hr.) | P | | | S | | P | | | |
| | Planned Start (Calendar Time) | | | | | | | | | |
| | Planned Finish (Calendar Time) | | | | | | | | | |
| **Facility Component** | Name | P | | | | | | | | S |
| | Description | P | | | | | | | | S |
| | Unit Rate ($/hr) | | | | | | | | | |
| | ATD ($) | P | | | | | | | | |
| | ATD(hr) | P | | | | | | | | |
| | Availability | P | | | S | | | | | |
| | Planned Start (Calendar Time) | | | | | | | | | |
| | Planned Finish (Calendar Time) | | | | | | | | | |
| **Facility Component Use** | Name | P | S | S | S | | S | | | |
| | ID | P | | | | | | | | |
| | Description | P | S | S | S | | S | | | |
| | Usage | P | | | | | | | | |
| | % Usage | P | | | | | | | | |
| | OB ($) | | | | S | S | P | | | |
| | OB (hr.) | | | | S | S | P | | | |
| | CB ($) | | | | S | P | | | | |
| | CB (hr.) | | | | S | P | | | | |
| | ATD ($) | P | | | S | | P | | | |
| | ATD (hr.) | P | | | S | | | | | |
| | Planned Start (Calendar Time) | | | | | | | | | |

| | | Federate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IICSS Object Class** | **Attributes** | Resources Control 4 | Cost Control 4 | Hour Control 4 | Schedule Control 4 | Change Management 4 | Cost Estimate 4 | Resources Control 3 | Schedule Control 3 | Document Management3 |
| | Planned Finish (Calendar Time) | | | | | | | | | |
| **Management Object** | ATD Resources ($) | | S | | P | | | | | |
| | ATD Resources (hr) | | S | | P | | | | | |
| | ATD Actors ($) | | S | | P | | | | | |
| | ATD Actors (hr) | | S | | P | | | | | |
| | ATD Facility Components($) | | S | | P | | | | | |
| | ATD Facility Components(hr) | | S | | P | | | | | |
| | ATD Component Total($) | | S | | P | | | | | |
| | ATD Component Total (hr) | | S | | P | | | | | |
| | EV Component Total ($) | | | | P | | | | | |
| | EV Component Total (hr.) | | | | P | | | | | |
| | EV Overall ($) | P | | | | | | | | |
| | EV Overall (hr.) | P | | | | | | | | |
| | EAC Component Total ($) | | P | | | | | | | |
| | EAC Component Total ($) | | P | | | | | | | |
| | ATD Component FTEs | | | S | P | | | | | |
| | ATD Total FTEs | P | | S | | | | | | |
| | PF Component Total (hr) | | | | P | | | | | |
| | PF Component Total ($) | | | | P | | | | | |
| | Rework (hr) | S | S | S | | | | | | |
| | EAC Rework (hr) | S | | | | | | | | |
| | Qualitative Risk Score | P | | | | | | | | |
| | Quality Control Inspection | P | | | | | | | | |
| | Unit Rate Component ATD ($/hr) | | | | P | | | | | |
| | Unit Rate Component EAC ($/hr) | | | | P | | | | | |

a) Objects Classes & Data Types



b) Interactions Classes

**Figure 4.3 : IICSS FOM**

The OMT editor creates the FOM for IICSS for all levels. Figure 4.3 describes the FOM for abstract level 4 as an example of other abstract levels. The OMT editor defines also the following:

- Data types of attributes values including enumerated data types
- Object classes as shown in Table 4.1

- Interactions classes

**Design LPs Algorithm for Federates**

The following step is to design the LPs algorithm for each federate using the time-stepped simulation engine. Appendix 4 describes the LPs of five federates at the abstract level 4 as a sample. User-interfaces have been designed as shown in Figures 4.4 to ease and demonstrate the IICSS system design. Figure 4.4 demonstrates the user interfaces for the schedule control federate as an example.

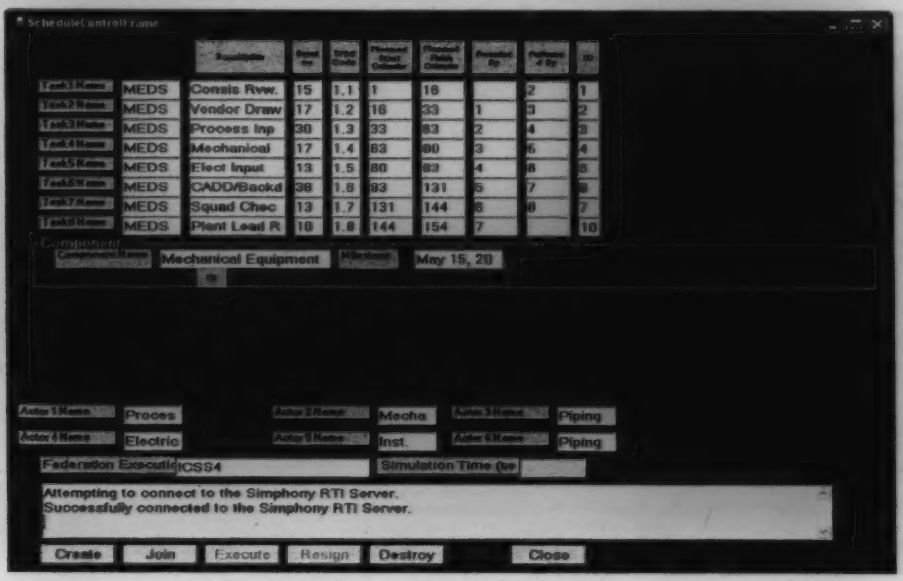

ScheduleControlFrame
MEDS Consis Rvw. 15 1.1 1 16 2 1
MEDS Vendor Draw 17 1.2 16 33 1 5 2
MEDS Process Inp 30 1.3 33 63 2 4 3
MEDS Mechanical 17 1.4 63 80 3 6 4
MEDS Elect Input 13 1.5 80 93 4 8 5
MEDS CADD/Backd 38 1.6 93 131 5 7 6
MEDS Squad Chec 13 1.7 131 144 6 8 7
MEDS Plant Lead R 10 1.8 144 154 7 10
Mechanical Equipment
May 15, 20
Proces
Mecha
Piping
Electric
Inst.
Piping
Federation Executi ICSS4
Simulation Time (se
Attempting to connect to the Simphony RTI Server.
Successfully connected to the Simphony RTI Server.
Create
Join
Execute
Resign
Destroy
Close

**Figure 4.4 : User-interface of Schedule Control Federate at Abstract Level 4**

The user interface includes the objects and their attributes of each federate. Also it includes an interface showing the results of the simulation run and steps for creating and joining the federation. The next step is to apply a case type on this prototype as described in the next section.

**Prototyping**

At this stage, a prototype simulation model has been designed, first using Excel sheet to illustrate the model and prove the developed LPs algorithms. The model consists of various worksheets. Every worksheet illustrates one of the federates as shown in Figure 4.6. The model defined times spots during project execution, when hour or cost performance factor is less than 0.95 or more than 1.1. It defines also when cashflow is more than approved budget, and when the deliverables are expected to be available in the document management system. The second step is to develop the simulation model using Simphony (AbouRizk, and Hajjar, 1998). The model used the same logical algorithms as described previously. The application of the model on the following case study proved the importance of this new approach.

## 4.5. CASE STUDY

The case study applied is the PSI project (Syncrude 2005). Syncrude Canada Ltd. (SCL) is enhancing its current Loss Management Program by incorporating the Process Safety Management (PSM) program concepts into its working practices. PSM is a multi-component, interdependent program aimed at reducing loss time incidents. The PSM program consists of several elements. The main element of this program is the Process Safety Information (PSI) project. PSI is implemented by CoSyn Technology. PSI is a collection of complete and accurate written information concerning process chemicals, process technology and process equipment. It is a process for documenting and communicating information on hazardous processes, equipment, and materials. The aim

of the PSI project is to verify and update the documentation required to support PSM, including various drawings, specifications/data sheets, and databases.

**Needs for Simulation Application**

This project applies several tools of project control, including cost estimation class II, planning, scheduling, cash flow table, performance factor index, documentation management, change management, milestone matrix, and others. Various levels of abstracts are applied with these tools which rolled up to higher level of abstract for the purpose of company control. The lack of information integration between these control tools requires and consumes more effort and time from the project control team. One example of this disintegration is the existence of different language used to create cost estimation versus the language used to build schedules or progressing. The first one is used to track the hour and cost performance factor of a project, while the second one is used to track the resource loading and schedule performance. At the same time, the need for simulation application is necessary to verify the following:

1) Apply what-if scenarios for various project control issues, such as budget constraint, time constraint, and others.
2) Training tools for project control and the project management team. This could help them to Figure out when the performance factor is under or over the specified limitation. These tools can also indicate when various deliverables can be available with limited resources, actors, and facility components.
3) Utilization patterns of resources, actors, and facility components could be determined using simulation as well.

4) Tracking of various uses for all actors, resources, and facility components is a good indicator to optimize the schedule structure and the logical relationships to use in order to optimize their utilization.
5) Simulation is also a good tool to incorporate historical data and lessons learned to this case study.

To apply the traditional simulation techniques to this case study and in general to construction and engineering projects would be both costly and time-consuming. The integration of project control tools under the same simulation model could not be achieved using the traditional simulation techniques. As well, the ability to differentiate between the various types of resources (actors, resources, and facility components) and their uses with different tasks is difficult to achieve with the traditional simulation techniques.

The next sections explain the main simulation objects used in this case study, describe the excel prototype, *Simphony* simulation models, and analyse their results.

**Main Simulation Elements**

The project consists of several segments. Each segment represents a project under PSI in terms of the schedule structure and 2 sections in terms of cost estimate class two structure (Expense vs. Capital). The project has four abstract levels within the company as follows:

- Stewardship Report (abstract level 1)
- PSI Monthly Report (abstract level 2)
- PSI Biweekly Report (abstract level 3)
- PSI Weekly Report (abstract level 4)

The developed prototype model describes the system at abstract level 4 and abstract level 3 only. These levels are our case study describing the main deliverables of PSI and their related tasks, estimates, and all types of resources. The same approach could be applied in same way to all PSI objects in the four abstract levels as described in chapter 3. The structure of some IICSS objects at abstract level 4 and their matching objects in PSI is as follows:

Case Study Objects Description:

**Component**: Process Flow Diagrams (PFDs)
System Diagrams (SDs)
Material Diagrams (MDs)
..... and others

**Actor**: Process
Mechanical
Piping
Electrical
Instrumentation & Control Systems

**Actor Use**: Process Use
Mechanical Use
Piping Use
Electrical Use
Instrumentation & Control Systems Use

**Task**: Tasks required to create each deliverable (Component)

**Milestone**: Start PSI M1

Field Verification Package To Site M2

Field Verification Package from site M3

Squad Check M4

Issued As Found (IAF) Complete M5

Turnover to DC&M M6

IAF Complete M7

Package Complete, Issue Package to SCL M8

**Document**: Field Verification Package

Squad Check Package

Engineering Package

**Location**: Home Office

Site Office

**Resource**: Expense

Capital

Expense related to Capital

**Resource Use**: Expense Use

Capital Use

Expense related to Capital Use

**Facility Component**: Camp (Field Staff)

Modular Units

Expenditure

**Facility Component Use**: Camp (Field Staff) Use

Modular Units Use

Expenditure Use

**Management Object**: Earned (hours)

Earned ($)

Actual To Date (hours)

Actual To Date ($)

The designed PSI model is shown in Figure 4.6 using the developed prototype system applied by Excel sheets for the illustration. The model illustrates the simulation model for one of the components (PFDs) in abstract level 4 as an example. The same approach could be applied to other components. It includes the following:

**Actors**: Instrumentation, Piping, and Process.

**Tasks**: Review – Process Consistency Check – CADD – Squad Check

**Milestone**: M4 Squad Check Complete

**Document**: PFDs Squad Check Complete

**Location**: Home Office

**Resource**: Field Staff

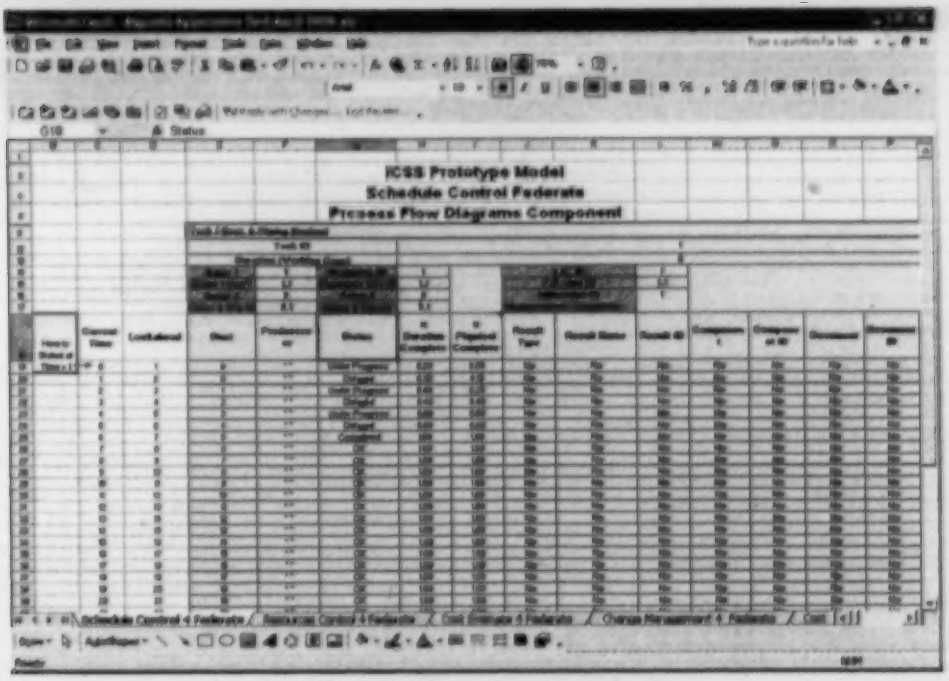
**Resource Use**: Field Staff Use

**Facility Component**: Expenditure

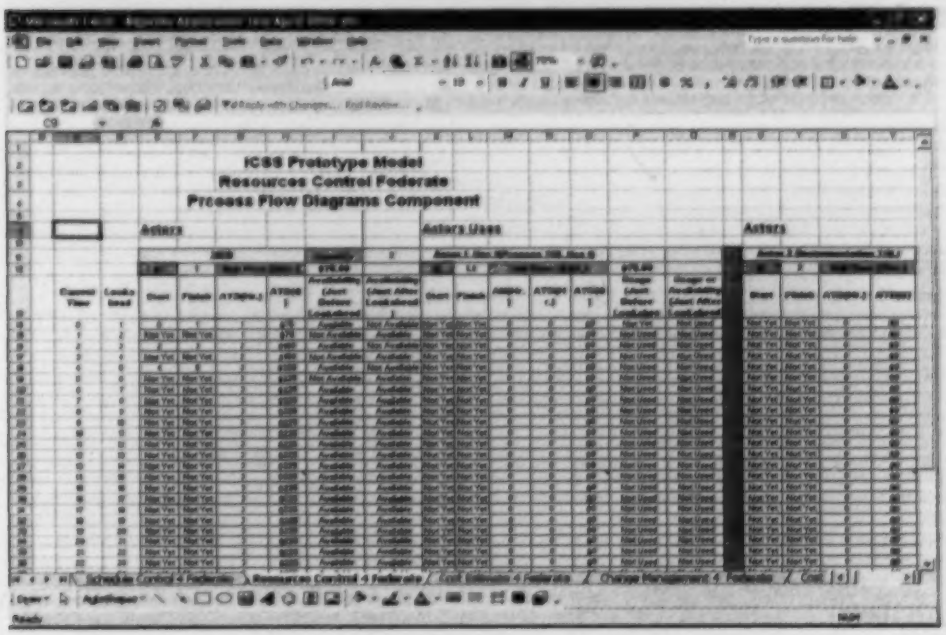
**Facility Component Use**: Expenditure Use

**Result**: PFDs Squad Check Document as a new resource.

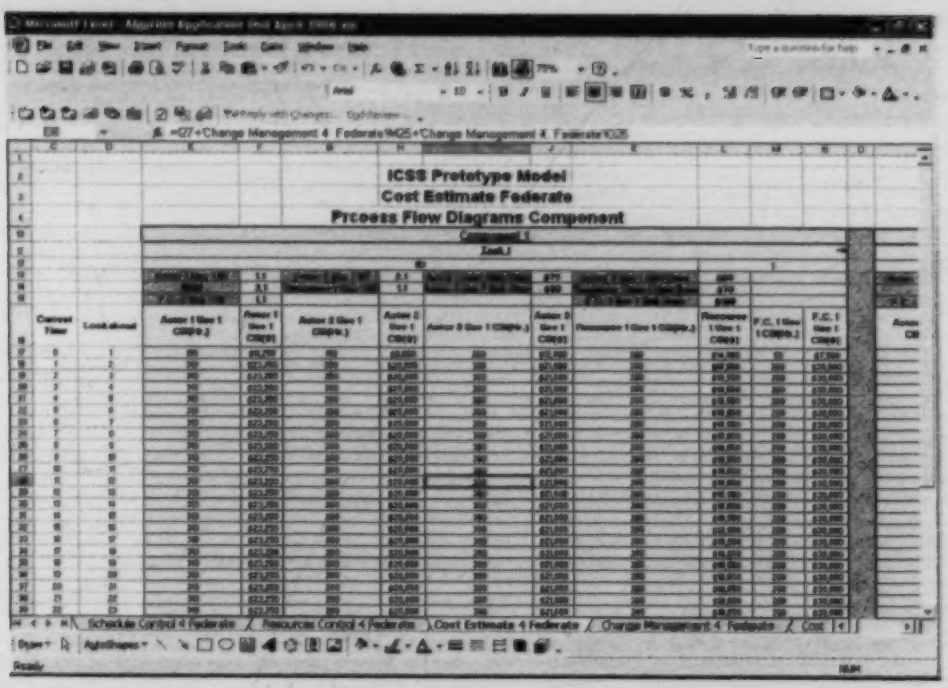
Another model developed is shown in Figure 4.6 using *Simphony*. The need to have an automated method to control the automated interactions of these elements together in order to produce elements at a higher level is yet unfulfilled. The availability to check the required elements at the same level in order to secure precise and accurate running of the simulation model for construction management is also still required. This will be discussed and outlined as a conceptual model for future research work in the following paper.



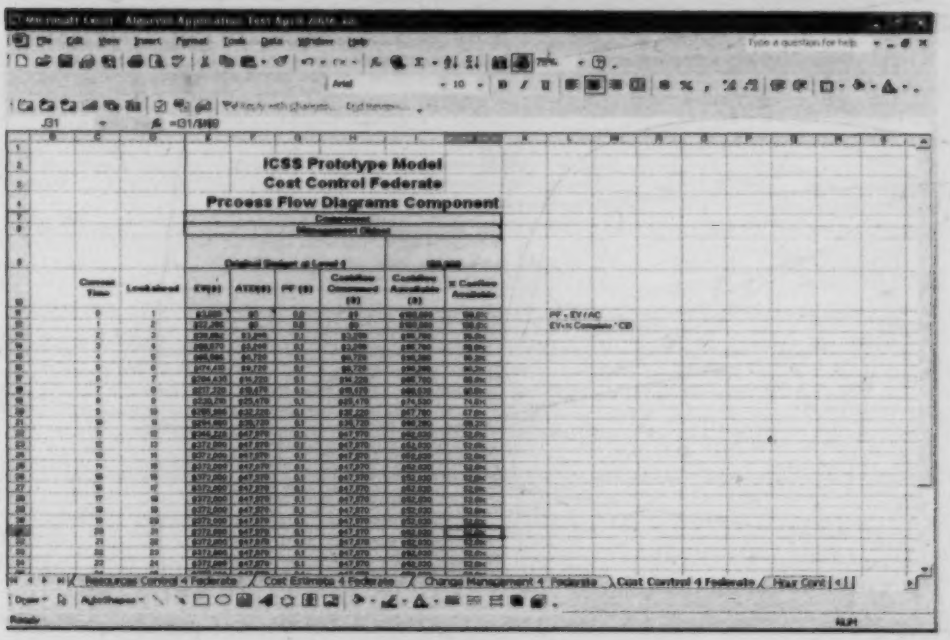

a) Schedule Control Federate




b) Resources Control Federate




c) Cost Estimate Federate




d) Cost Control Federate

**Figure 4.5 :Prototype Model**

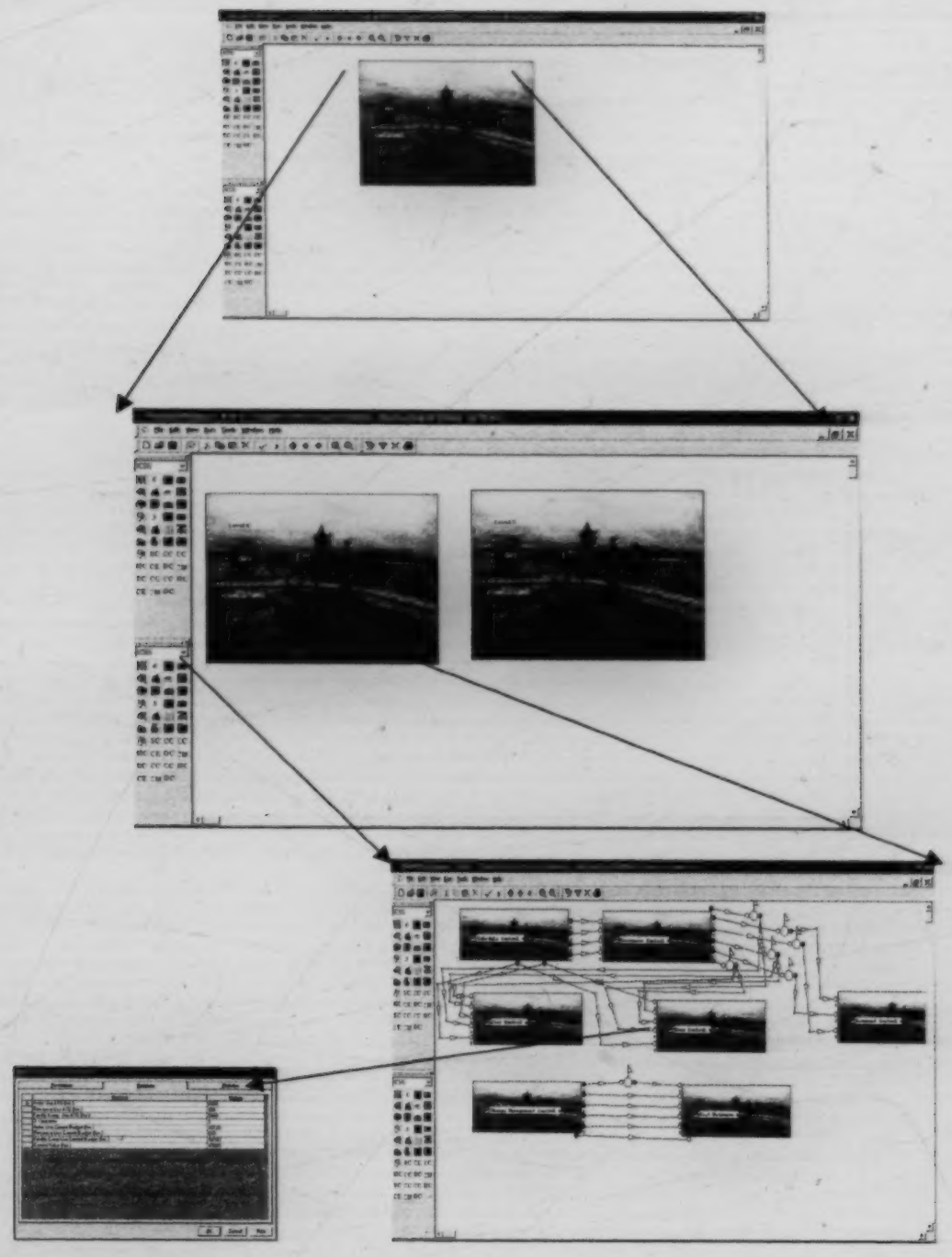
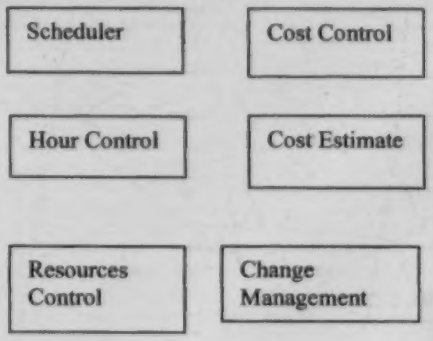
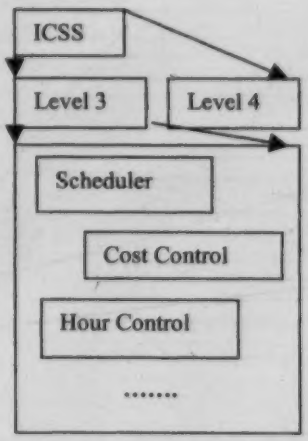


**Figure 4.6 : Prototype Model using Simphony**

**Results and Importance of New Approach**

Traditional techniques can simulate this same case study. Table 4.1 describes the simulation model contents, using the traditional techniques, and the information that could be collected using this approach, with comparison to the developed model for the same case study, as well as information that could be collected during and following the simulation run.

**Table 4-2 :Comparison of Developing Integrated Simulation Model using Traditional Method and New Approach**

| Item | Traditional Method | New Method |
|---|---|---|
| **Data Hierarchy** | Not achieved | Achieved |
| **Reusability** | Rarely | Applicable |
| **Industry Ontology** | Not used | Applied |
| **Information Flow** | Limited | Smooth |
| **Management Areas Information Integrity** | Not existed | Existed |
| **Model Complexity** | High. There is a need to develop an application and simulation model for every management control area, and connect them later. The same will be repeated for every abstract level of management.   | Limited. Only one main element will be developed. All other children elements exist and will be developed together.   |

## 4.6. CONCLUSIONS

The prototype system developed fulfills the major functions of the distributed information-based methodology. This chapter walks through the steps used to develop IICSS using HLA. It presents the concept of information-oriented simulation integrated with the distributed simulation system, and demonstrates that IICSS provides a simple and straight forward way to integrate construction management processes and introduce results for all end-users. The system was built using the time-stepped distributed simulation, which matches the updating of progress data of construction management processes in reality at cutoff dates. IICSS is flexible enough to simulate complex construction management processes without additional coding.

## 4.7. REFERENCES


- Boer, C.A., and Verbraeck, A. (2003). "Distributed Simulation with COTS Simulation Packages." Proceedings of the 2003 Winter Simulation Conference.
- Fujimoto, R.M. (2003). "Distributed Simulation Systems." Proceedings of the 2003 Winter Simulation Conference.
- Kuhl, F., Weatherly, R., and Dahmann, J. (1999). "Creating Computer Simulation system: An introduction to the High Level Architecture." Prentice Hall, NJ.
- McLean, C., Harrell, C., Zimmerman, P.M., and Lu, R.F. (2003). "Simulation Standards: Current Status, Needs, and Future Directions." Proceedings of the 2003 Winter Simulation Conference.

- Schulz, T., and Wytzick, A. and Raape, U. (2002). "Distributed SPATIO_Temporal Modeling and Simulation." Proceedings of the 2003 Winter Simulation Conference.
- Syncrude LTD. (2005). "Process Safety Information Project." Canada.

# APPENDIX 1 – DESCRIPTION OF FEDERATES

Resources Control Federate:

It describes the processes required to control labor, material, and equipment of the construction or engineering project in the most effective way.

Cost Control Federate:

It describes the processes required to control the cost of the construction or engineering project to ensure that the project is executed within the approved dollar budget.

Hour Control Federate:

It describes the processes required to control the time of the construction or engineering project to ensure that the project is executed within the current hour budget.

Schedule Control Federate:

It describes the processes required to control the schedule of the project to ensure that the project is executed within the approved time boundaries.

Change Management Federate:

It describes the processes required to control any project trend (trend, change order, and/or budget shift) for the construction or engineering project in the most effective way.

Cost Estimate Federate:

It describes the processes required to estimate the time and dollars required for the construction or engineering project to be executed within the required scope, time frame, and quality.

Document Management Federate:

It describes the processes required to control all the documents related to the construction or engineering project in the most effective way. These documents could either be deliverables of the project or requirements for the proper execution of the project.

## APPENDIX 2 – LPs OF IICSS4 FEDERATES

### 4.1 Schedule Control Federate (SCF) at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

At level 4, we could have more than Schedule Control Federate because they represent components at this level. While we could have only one federate of Cost Estimate, Cost Control, Hour Control, Resources Control, Document Control & Change Management. Everyone of these federates represent all components at this level.

Input initial value of attributes by user or database for all elements

Create all tasks & other objects (elements)

Start Simulation

Set Current time to Zero

While not (end of simulation) do

For all Tasks

**' It is assumed that type of relationship between Tasks is only FTS**

**'Check if start of task is between current time + time step**

If Task.preceded by = " " and Task.Status ="InComplete" or Task.Status of preceded task = "Completed" and Task.Status = "Not Started, Delayed, or Under-Progress"

**'Resources Availability Checking**

Send message # 1 to Resources Control Federate (RCF)

asking for related actors (by ID) availability

If Actor. Availability = "available"

**' Resources Control Federate Changes related actors "Availability" attribute value ' to "Not Available" & Create Actor Use**

Go to resource uses (10)

Else

Change Task "Status" attribute values = "Delayed"

Wait for actors uses to be available

Exit For

(10) Send message # 2 to Resources Control Federate asking for related resources uses availability

If Resource. Availability = "available"

**' Resources Control Federate Changes related resources "Availability" 'attribute value to "Not Available" & Create Resource Use**

Go to facility component Uses (20)

Else

Change Task "Status" attribute values = "Delayed"

**' Resources Control Federate Changes related actors "Availability" attribute 'value to "Available"**

Send message # 4 to Resources Control Federate asking for changing related Actors.Availability to "Available"

Wait for resources uses to be available

Exit For

(20) Send message # 3 to Resources Control Federate asking for related facility components uses availability

If available

**' Resources Control Federate Changes related facility components "Availability" attribute value to "Not Available" & Create Facility 'Components Uses**

Go to (30)

Else

Change Task "Status" attribute values = "Delayed"

**' Resources Control Federate Changes related actors "Availability" attribute value ' to "Available"**

Send message # 5 to Resources Control Federate asking for changing related Facility Components.Availability to "Available"

Wait for facility components uses to be available

Exit For

(30) Calculate finish of Task = start of Task + duration of Task

**' Resources Control Federate Changes related actors, resources & facility ' components "Availability" attribute value to "Available"**

% Duration Complete of Task = (Current Time + Time Step – Task.Start ) / (Current Time + Time Step -Task.Start + Remaining Duration)

**' Where Remaining Duration Can be defined by user at required time or generated randomly, or assumed to equal Task.Duration - (Current Time + Time Step - Task.Start)**

If % complete = 100%

Change Task "Status" attribute value to "Completed"

Else

Task.Status = "Under-Progress"

End if

Check if there is milestone succeeds this Task

Calculate Date of Milestone = Finish date of this Task

For all Results

Check related Results by "ID" attribute value of Result

Update Results "Finish" attribute value = Task.Finish

If Result.TypeOf = Resource

Send message # 7 to Resources Control Federate to add it to list of resources

Else

Send message # 8 to Resources Control Federate to add it to list of facility components

End If

Next

For all Components

Check related Component by "ID" attribute value of

```
        Component
        Update Component "Start" attribute values = Task.Start
        Update Component "Finish" attribute values = Task.Finish
        If Component.Finish  NOT = "  "
                Component. Availability = "available"
        Else
                Component.Availability = "not available"
        End If
Next

For all Documents
        Check if Task relates to Document by "ID" attribute value of
        Document at Document Control Federate
        Update Component "LastRevisionTime" attribute values =
        Task.Finish
        Send message to Document Control Federate to update
        related Document
Next
For all Management Objects
        Check related Management Object "ID" attribute value of
        Management Object
        Send message # 9 to Resources Control Federate to check
        related resources uses
```

Calculate ATD (hrs.) of resources = Total of ATD(hr.) of related resources uses

Calculate ATD ($) of resources = Total of ATD($) of related resources uses

Send message # 10 to Resources Control Federate to check related actors uses

Calculate ATD (hrs.) of actors = Total of ATD(hr.) of related actors uses

Calculate ATD ($) of actors = Total of ATD($) of related actors uses

Send message # 11 to Resources Control Federate to check related facility components uses

Calculate ATD (hrs.) of facility components = Total of ATD(hr.) of related facility components uses

Calculate ATD ($) of facility components = Total of ATD($) of related facility components uses

Calculate ATD Component Total (hrs.) = Total of all previous uses ATD (hrs.)

Calculate ATD Component Total ($) = Total of all previous uses ATD ($)

'Assuming Time Step = 1 and equals to 1 week

Calculate workable hours = Current Time * 40

ATD Component FTEs = ATD (hr.) of Actors / workable Hours

Send message to Change Management Federate to check CB (hr.) of actors uses

Send message to Change Management Federate to check CB (hr.) of resources uses

Send message to Change Management Federate to check CB (hr.) of facility components uses

Calculate CB Component Total (hr.)

Get % Physical Complete of Component (by user or data base or random number)

Calculate EV Component Total (hr.) = CB Component Total (hr.) * % Physical Component

Calculate PF Component Total (hr.) = EV Component Total (hr.) / ATD Component Total (hrs.)

**' The same as above will be repeated for PF Component Total ($)**

**' Assume one method for calculating EAC**

Calculate EAC Component Total (hr.) = ATD Component Total (hr.) + ( CB Component Total (hr.) – EV Component Total(hr.))

Calculate EAC Component Total ($.) = ATD Component Total ($.) + ( CB Component Total ($.) – EV Component Total($) )

**'Calculation of Unit Rate Component Total ($/hr.)**

Calculate ATD Unit Rate Component Total ($/hr.) = ATD Component Total ($) / ATD Component Total (hr.)

Calculate EAC Unit Rate Component Total ($/hr.) = EAC Component Total ($) / EAC Component Total (hr.)

Next

Else IF

Task.Status = Completed or Task. % Duration Complete = 100 %

Send message # 6 to RCF to change Status for all related Actors, Resources, Facility Components to " Available".

Next

End While

End Simulation

## 4.2 Hour Control Federate at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

Input initial value of attributes by user or database for all elements

Create Management Object (elements)

Start Simulation

Set Current time to Zero

While not (end of simulation) do

For all Management Objects (If exists more than one object)

Get Original Budget (hr.) = Sum of Original Budgets (hr.) for all Tasks at Cost Estimate Federate

**'Calculate EV Overall (hr.), AC(hr.) & PF(Hr.) for level 4 (All components)**

**'Assume % Physical Complete is the same for all Tasks as component for simplicity of illustration. It is entered manually as constant number or distributed function to match developed scenario.**

Get % Physical Complete for every task's Resources, Actors & Facility Components from Schedule Control Federates

Get Current Budget (hr.) for all Resources, Actors & Facility Components from Cost Estimate Federate

EV Overall (hr.) = Sum of (% Physical Complete * related Current Budget of Resources, Actors & Facility Components)

Get ATD (hr.) for all Uses of Resources, Actors & Facility Components from Schedule Control Federates

AC Overall (hr.) = Sum of (ATD (hr.) of all Actor Uses, Resources Uses, Facility Components Uses)

PF Overall (hr.) = EV Overall (hr.) / AC Overall (hr.)

Budget Consumed (hr.) = AC Overall (hr.)

Budget Available (hr.) = Original Budget (hr.) - Budget Consumed (hr.)

% Budget Available (hr.) = Budget Available (hr.) / Original Budget (hr.)

Next

End While

End Simulation

## 4.3 Cost Control Federate at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

Input initial value of attributes by user or database for all elements

Create Management Object (elements)

Start Simulation

Set Current time to Zero

While not (end of simulation) do

For all Management Objects (If exists more than one object)

Get Original Budget ($) = Sum of Original Budgets ($) for all Tasks at Cost Estimate Federate

**'Calculate EV Overall ($) , AC($) & PF($) for level 4 (All components)**

**'Assume % Complete is the same for all Tasks as component for simplicity of illustration. It is entered manually as constant number or distributed function to match developed scenario.**

Get % Physical Complete for every task's Resources, Actors & Facility Components from Schedule Control Federates

Get Current Budget ($) for all Resources, Actors & Facility Components from Cost Estimate Federate

EV Overall ($) = Sum of (% Physical Complete * related Current Budget of Resources, Actors & Facility Components)

Get ATD ($) for all Uses of Resources, Actors & Facility Components from Schedule Control Federates

AC Overall ($) = Sum of (ATD ($) of all Actor Uses, Resources Uses, Facility Components Uses)

PF Overall ($) = EV Overall ($) / AC Overall ($)

Cashflow Consumed ($) = AC Overall ($)

Cashflow Available ($) = Original Budget ($) - Cashflow Consumed ($)

% Cashflow Available ($) = Cashflow Available ($) / Original Budget ($)

Next

End While

End Simulation

## 4.4 Resources Control Federate (RCF) at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 week

```
Input initial value of attributes by user or database for all elements
Create all tasks & other objects (elements)
Start Simulation
Set Current time to Zero
While not (end of simulation) do
IF SCF send message # 1 to RCF
    For all Actors
        If Actor.ID = SCF.requiredActor.ID
            If Actor.Availability ="Available"
                Change Actor.Availability ="Not Available"
                Change Actor.related ActorUse.Usage = "Used"
                RCF reply to SCF for Actor .Availability="Available"
            Else
                RCF reply to SCF for Actor .Availability="Not Available"
            End If
        End If
    Next
End If
```

```
IF SCF send message # 2 to RCF
    For all Resources
        If Resource.ID = SCF.requiredResource.ID
            If Resource.Availability ="Available"
                Change Resource.Availability ="Not Available"
                Change Resource.related ResourceUse.Usage = "Used"
                RCF reply to SCF for Resource .Availability="Available"
            Else
                RCF reply to SCF for Resource .Availability="Not
                    Available"
            End If
        End If
    Next
End If

IF SCF send message # 3 to RCF
        For all Facility Components
            If Facility Component.ID = SCF.requiredFacility Component.ID
                If Facility Component.Availability ="Available"
                    Change Facility Component.Availability ="Not Available"
                    Change Facility Component.related Facility
                    ComponentUse.Usage = "Used"
```

RCF reply to SCF for Facility Component

.Availability="Available"

Else

RCF reply to SCF for Facility Component

.Availability="Not Available"

End If

End If

Next

End If

```
IF SCF send message # 4 to RCF
        For all Actors
                If Actor.ID = SCF.requiredActor.ID
                        Change Actor.Availability ="Available"
                        Change Actor.related ActorUse.Usage = "Not Used"
        End If
        Next
End If

IF SCF send message # 5 to RCF
        For all Resources
                If Resource.ID = SCF.requiredResource.ID
                        Change Resource.Availability ="Available"
                        Change Resource.related ResourceUse.Usage = "Not Used"
        End If
        Next
End If

IF SCF send message # 6 to RCF
    For all Actors
        If Actor.ID = SCF.requiredActor.ID
                Change Actor.Availability ="Available"
```

```
                Change Actor.related ActorUse.Usage = "Not Used"
        End If
    Next

    For all Resources
                If Resource.ID = SCF.requiredResource.ID
                        Change Resource.Availability ="Available"
                        Change Resource.related ResourceUse.Usage = "Not Used"
            End If
    Next

    For all FacilityComponents
                If    Facility Component.ID = SCF.requiredFacility Component.ID
                        Change Facility Component.Availability ="Available"
                        Change Facility Component.related Facility
                        ComponentUse.Usage = "Not Used"
                End If
    Next

    End If

    If SCF send message # 7 to RCF
            Add new Result as Resource
```

End If

If SCF send message # 8 to RCF

Add new Result as Facility Component

End If

If SCF send message # 9 to RCF

For all ActorUses

If ActorUse.ID = Component.Task.ActorUse.ID

ActorUse.ATD(hr.) = Count # of TimeSteps Where

ActorUse.Usage = " Used"

ActorUse.ATD($) = Count # of TimeSteps Where

ActorUse.Usage = " Used" * ActorUse.Actor.UnitRate ($/hr.)

' Unit Rate ($/hr.) of Actor is received from Cost Estimate Federate

End If

Next

End If

If SCF send message # 10 to RCF

For all ResourceUses

If ResourceUse.ID = Component.Task.ResourceUse.ID

ResourceUse.ATD(hr.) = Count # of TimeSteps Where

ResourceUse.Usage = " Used"

ResourceUse.ATD($) = Count # of TimeSteps Where

ResourceUse.Usage = " Used" *ResourceUse.Actor.UnitRate ($/hr.)

**' Unit Rate ($/hr.) of Resource is received from Cost Estimate Federate**

End If

Next

End If

If SCF send message # 9 to RCF

For all FacilityComponentUses

If FacilityComponentUse.ID =

Component.Task.FacilityComponentUse.ID

FacilityComponentUse.ATD(hr.) = Count # of TimeSteps Where

FacilityComponentUse.Usage = " Used"

FacilityComponentUse.ATD($) = Count # of TimeSteps Where

FacilityComponentUse.Usage = " Used" *

FacilityComponentUse.Actor.UnitRate ($/hr.)

**' Unit Rate ($/hr.) of FacilityComponent is received from Cost Estimate Federate**

```
            End If

        Next

End If
```

## 4.5 Cost Estimate Control Federate at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

Input initial value of attributes by user or database for all elements

Create all Tasks, Actor Uses, Resources Uses & Facility Components Uses

'Unit Rate & ID for all Uses as well as ID for Tasks are entered here initially

Start Simulation

Set Current time to Zero

While not (end of simulation) do

For all Tasks

If Current time = 0

Actor Use CB (hr.) = Actor Use OB (hr.) '**OB is an Input by user**

Actor Use CB ($) = Actor Use OB (hr.) * Actor Use unit Rate ($/hr.)

Resource Use CB (hr.) = Resource Use OB (hr.) '**OB is an Input by user**

Resource Use CB ($) = Resource Use OB (hr.)*Resource Use unit Rate ($/hr.)

Facility Component Use CB (hr.) = Facility Component Use OB (hr.)

'**OB is an Input by user**

Facility Component Use CB ($) = Facility Component Use OB (hr.) *

Facility Component Use unit Rate ($/hr.)

Else

Get BS & Trend (hr.), CO (hr.) , BS & Trend ($) & CO($) from Change

Management Federate

Actor Use CB (hr.) = Actor Use CB (hr.) + Actor Use BS & Trend (hr.) +
Actor Use CO (hr.)

Actor Use CB ($) = Actor Use CB ($) + Actor Use CO ($)

Resource Use CB (hr.) = Resource Use CB (hr.) + Resource Use BS & Trend (hr.) + Resource Use CO (hr.)

Resource Use CB ($) = Resource Use CB ($) + Resource Use CO ($)

Facility Component Use CB (hr.) = Facility Component Use CB (hr.) +
Facility Use CO (hr.)

Component Use BS & Trend (hr.) + Facility Component Use CO (hr.)

Facility Component Use CB ($) = Facility Component Use CB ($) + Facility Component Use CO ($)

End If

Next

End While

End Simulation

## 4.6 Change Management Federate at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

Input initial value of attributes by user or database for all elements

Create all Tasks, Actor Uses, Resources Uses & Facility Components Uses

'Unit Rate & ID for all Uses as well as ID for Tasks are entered here to match what is in Cost Estimate Federate

Start Simulation

Set Current time to Zero

While not (end of simulation) do

For all Tasks

**'Users enter manually his assumption for either Budget Shift ( BS) , Trend, or Change Order (hr.) for all actors, resources, facility components uses as either constant number or distributed number at specified time step to check any assumed assumption**

Actor Use BS & Trend ($) = Actor Use BS & Trend (hr.) * Actor Use Unit Rate ($/hr.)

Actor Use CO ($) = Actor Use CO (hr.) * Actor Use Unit Rate ($/hr.)

Resource Use BS & Trend ($) = Resource Use BS & Trend (hr.) * Resource Use Unit Rate ($/hr.)

Resource Use CO ($) = Resource Use CO (hr.) * Resource Use Unit Rate ($/hr.)

Facility Component Use BS & Trend ($) = Facility Component Use BS & Tren

(hr.) * Facility Component Use Unit Rate ($/hr.)

Facility Component Use CO ($) = Facility Component Use CO (hr.) * Facility Component Use Unit Rate ($/hr.)

Next

End While

End Simulation

## 4.7 Document Management Federate at Abstract Level 4

N.B: Simulation Engine used here is Time-Stepped engine

Assuming Time Step = 1 and equals to 1 Hour

Input initial value of attributes by user or database for all elements

Create all Documents

**'ID for all Documents are entered initially**

Start Simulation

Set Current time to Zero

While not (end of simulation) do

Get Documents ID & Name from Schedule Control Federate if Created or Updated during simulation run at every time step

For all Documents

If Schedule Control Federate. Result Type NOT= Document

Document. Name = "No Document"

Document. Updated Start Time = "Not Yet"

Document. Updated Finish Time ="Not Yet"

Else

If Schedule Control Federate. Document. ID = Document. ID

Document. Updated Start Time = Schedule Control Federate. Current Time

Document. Updated Finish Time = Schedule Control Federate. Lookahead Time

```
            End If
        End If
    Next
    End While
    End Simulation
```

# CHAPTER 5. IICSS AND NATURAL LAWS – NEW APPROACH

## 5.1. ABSTRACT

Chemical theories and principles that control the chemical structure and reactions of any substance or material in nature have the possibility of similarity with the information flow patterns in a construction management simulation system. This paper launches the idea of chemistry as a new field that needs to be discovered and used to enhance the building of a simulation system for construction management. A similarity comparison of structure and reactions between chemical elements and construction management simulation elements is introduced. This paper is an attempt to enhance the IICSS introduced in the previous papers and to increase its intelligence and reduce its limitations. A detailed conceptual design for a model that is built based on these similarities and can be used to enhance the IICSS is also discussed. A prototype model is illustrated to prove this approach. This also argues for potential future work in this area.

## 5.2. INTRODUCTION

Construction Simulation has been limited to a construction engineering perspective more than that of construction management. It was introduced first by Halpin (1973), with the development of the CYCLONE modeling system. It has been the basis for many other construction simulation systems including, but not limited to, INSIGHT (Paulson 1978), RESQUE (Chang 1987), UM-CYCLONE (Ioannou 1989), and HSM (Sawhney and

AbouRizk 1995). Researchers described the major obstacles to its use by industry as the complexity and time requirements involved in developing the model (Shi and AbouRizk 1997). Researchers introduced methods to limit these gaps including reusability, computer aided modeling, hierarchical, modular modeling system, resource-based simulation (Shi and AbouRizk 1997), and special-purpose simulation (AbouRizk and Hajjar 1998). Although these attempts offer an interactive and flexible construction simulation system, no one gave any attention to the information pattern and flow within it. As a result, models have to be rebuilt in every instance consuming more time and assuming the knowledge adequacy for the simulation models of the users and/or developers. The need to develop systematic realistic and effective patterns for the information flow in a construction simulation system is great and it would help address all these issues.

The goal of the research presented in this chapter is to investigate a new area, "chemistry laws and principles", as a potential area for modeling information structure and traffic in construction simulation modeling. This is achieved by analysing the area of similarity between the information pattern of a construction simulation system and the structure and reactions of certain chemical substances. This chapter is organized as follows. The following section reviews the main principles and theories of chemistry. The sections after that analyse the similarity between those principles and theories and the construction simulation system information patterns, as well as introduce a conceptual design for enhancing the IICSS structure. A prototype case study is introduced in the fifth section to explain this result. The sixth section introduces the potential of future work in this area, following by a summary of the research contribution.

## 5.3. REVIEW OF CHEMISTRY

In this section, a brief review of the main chemistry theories and principles that can enhance the information flow in construction simulation is introduced. The structure of elements in a chemistry environment and how they interact is declared. This section starts with reviewing the meaning of chemistry and its headlining history. The main theories and principles of atomic structure, the periodic table, the classification of chemical elements, and the atomic configuration tables are described. Types of chemical bonds as well as types of chemical reactions are outlined. The main definitions and terminology used in chemistry are also defined.

### 5.3.1. ORGANIZATION OF MATTER

The first step to understand well how chemistry works in nature is to understand the organization of matter as shown in Figure 5.1. Matter is defined as anything occupying space and having mass, which is the material of the universe (Zumdahl 2000). Most of matter consist of mixtures, which can be either homogeneous or heterogeneous. Homogeneous mixtures consist of pure substances, which consist of mainly compounds and elements. A compound (Figure 5.2) is a substance with constant composition that can be broken down into its elements by chemical processes (Zumdahl 2000). Elements are substances that cannot be decomposed into simpler substances by chemical or physical means. They are composed by atoms that include a nucleus and electrons with a negative charge. Nucleuses include protons with a positive charge and neutrons with no charge.

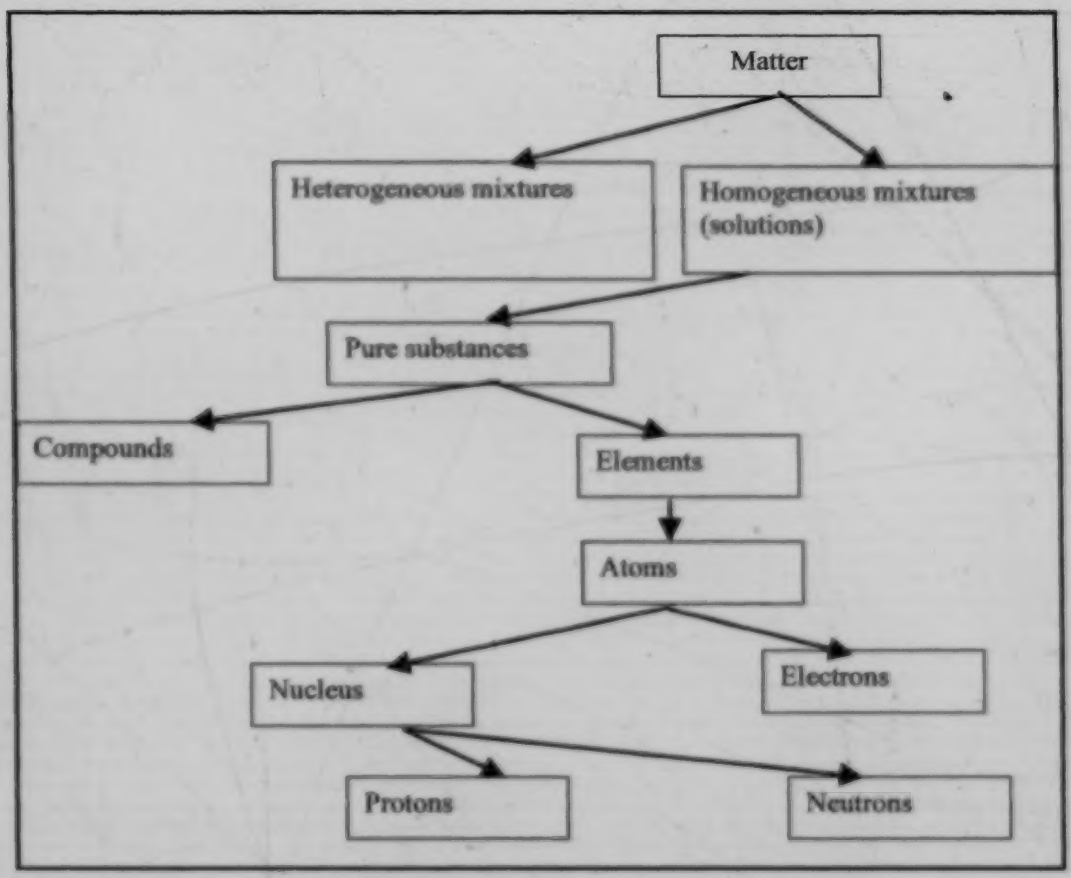
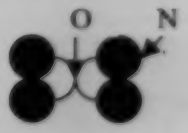



**Figure 5.1 : Organization of Matter (Zumdahl 2000)**




N/O = 4/2

**Figure 5.2 : Example Compound**

## 5.3.2. ATOMIC STRUCTURE THEORIES

One early model of quantum mechanics was the simplified **Bohr Atomic Model**, in which electrons are assumed to revolve around the atomic nucleus in discrete orbits, and the position of any particular electron is well defined in terms of its orbital The **Quantum Mechanical Model,** that was introduced later, assumes that electrons surround the nucleus in wave functions called orbitals.

## 5.3.3. ELECTRONIC CONFIGURATION TABLE

An electron configuration table is a type of code that describes how many electrons are in each energy level of an atom and how the electrons are arranged within each energy level. It packs a lot of information into a little space. Figure 5.3 shows the order of an orbital (energy level) around a polyelectronic atom, while Figure 5.4 illustrates two examples of the electronic configuration for the Boron (B) element and the Helium (He) element. Valence electrons are the electrons responsible for bonding in chemical reactions and occupy the outermost energy level around the atom.

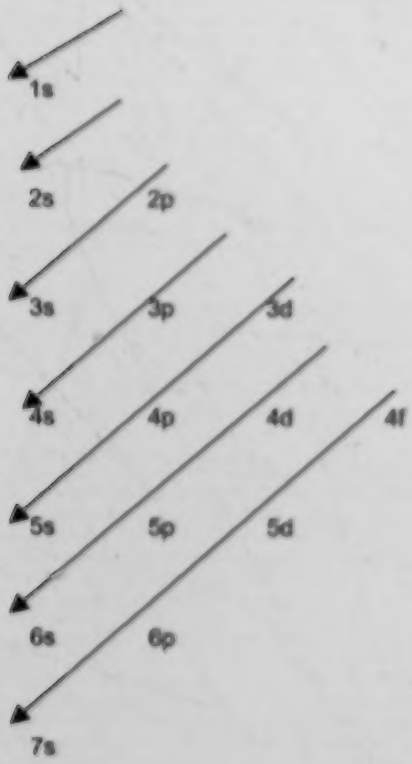



**Figure 5.3 : Order of orbital (energy level) around polyelectronic atom (Zumdahl 2000)**

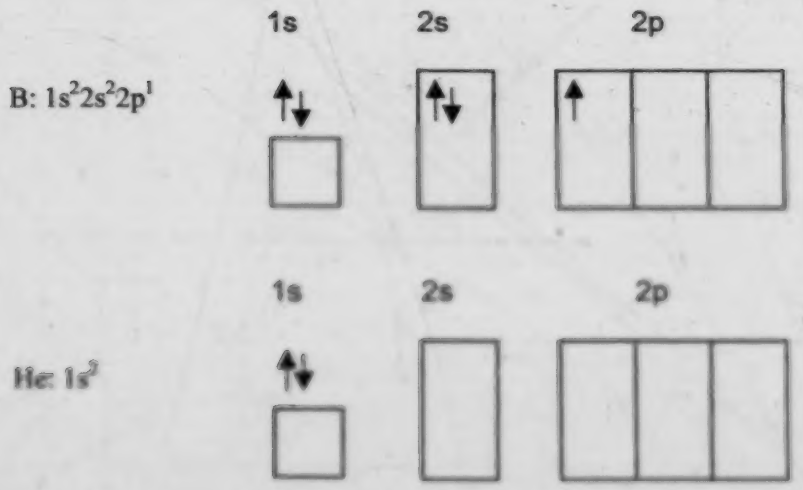



**Figure 5.4 : Electronic Configuration of Boron (B) & Helium (He) elements**

## 5.3.4. TYPES OF CHEMICAL ELEMENTS

Chemical elements are either Metals, Nonmetals, or Transition elements. Most of the elements are metals. They tend to loose electrons to form positive ions in chemical reactions. Nonmetals tend to gain electrons with metals to form negative ions in chemical reactions. Transition elements are elements that have both metallic and nonmetallic properties (semimetals).

## 5.3.5. PERIODIC TABLE

The periodic table is a type of chart that shows all of the known chemical elements and their properties. Each element has an atomic number, which indicates the number of protons for that specific element. The periodic table is arranged in such a way that

elements in the same column have similar properties, while horizontal rows are called periods. They start with the first period and so on. Figure 5.5 shows the periodic table (Zumdahl 2000). The table divides elements into metals, transition elements, and nonmetal elements. Each column has a label (1A to 8 A) which indicates the number of valence electrons for the elements in this group (column). Each row (period) has a number that indicates the highest occupied electron level.

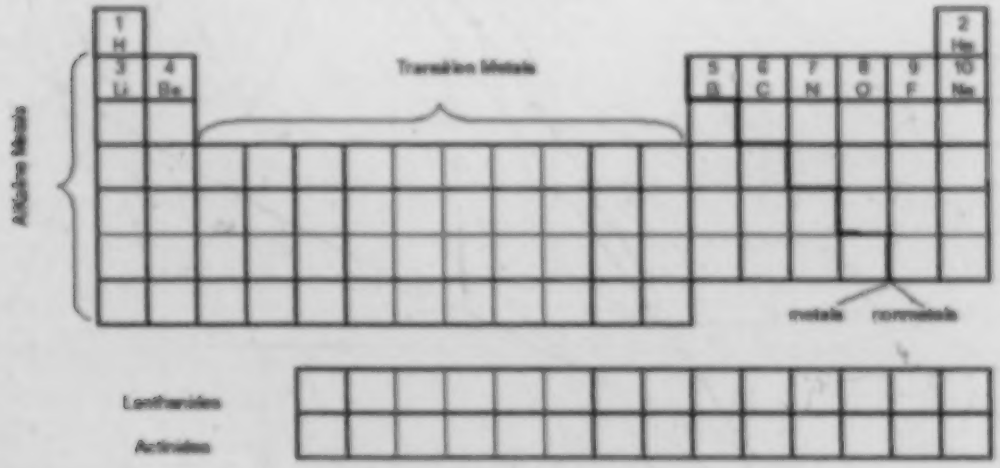


**Figure 5.5 : Periodic Table**

## 5.3.6. CHEMICAL BONDS & REACTIONS

There are several ways that atoms interact together in chemical reactions as shown in Figure 5.6. They are neither created nor destroyed. They are only **rearranged** in these reactions. The forces that hold atoms together in compounds (molecules) as shown in Figure 5.6 are called **chemical bonds.** The first type is the **Ionic Bond**. This happens when a metal reacts with a nonmetal. The nonmetal tends to gain electrons in this

reaction with the metal. The nonmetals often bond to each other by forming a **Covalent Bond**, in which electrons are shared between the atoms. The output of any chemical reaction is a chemical change, in which a given substance becomes a new substance or substances with different properties and different compositions.

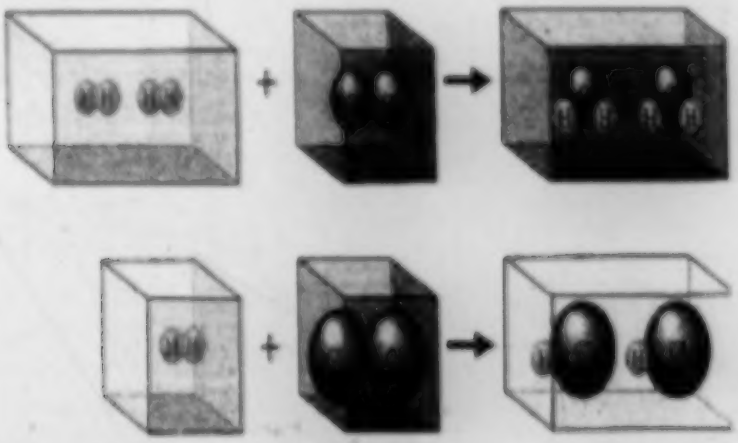


**Figure 5.6 : Molecules and Chemical Reactions (Zumdahl 2000)**

## 5.3.7.SUMMARY

From this brief review of certain chemistry principles and theories, we can conclude the following: the structure of the atoms for any of the natural elements affects the way that any of these elements interact with each other. The main part(s) of the element that is (are) responsible for this interaction is the valence electron(s) at the outer orbit. Also, we noticed that there are always negatively and positively charged parts inside any atom, electron, and proton, respectively, while neutrons have no charge. The elements interact together to reach the lowest energy level and to be likely more stable. Elements are classified as either metals (lose electrons), nonmetals (gain electrons), or transition

elements (lose or gain electrons). The bonds that hold these elements together are binary (between two elements only at any time), and can be ionic (transfer electron) or covalent (share electron).

## 5.4. COMPARISON OF CONSTRUCTION MANAGEMENT SIMULATION INFORMATION FLOW & CHEMICAL SYSTEM

### 5.4.1. INTRODUCTION

Modeling and simulation are not concerned only with the elements themselves but also with establishing certain relationships among them (Zeigler B. 1986).

Based on that, the simulation system should reflect the systematic pattern of relationships between its elements as well as possess a well-defined internal structure for those elements.

Some of the existing simulation languages in construction are basically developed based on an object oriented concept to control the interaction between the various elements of the model. The object oriented concept is based mainly on the vertical hierarchy approach, and does not reflect horizontal relationships.

On the other hand, none of the existing simulation languages could achieve all of the main essential criteria for a simulation model to be applied perfectly within construction management applications. One of these criteria is how to automatically combine elements during a simulation run in order to produce new elements. What the rules are, which control that, and how that can be achieved are 2 questions needing answers. Another

important issue is how the simulation elements can be automated enough to know each other, and know how they will interact with one another. This will answer, for example, the question of how an excavation truck element can know that it can interact, during a simulation run, with the soil element, while knowing it should not interact with the concrete element. What will be the output element (aggregate) as a result of interacting two or more elements together is also another important question that has not been well answered. Can the simulation model be automated enough to reflect the construction/project management processes output? All of these questions and struggles need to be solved.

The chemical environment, as we discussed, has a unique, impressive, and magnificent system that can be simulated to answer at least some of these unanswered questions. The next section will compare the main similarity between the elements structure and their interaction with chemical atoms and their chemical reactions. A proposed structured approach for applying the chemical theories and principles to IICSS will be outlined.

### 5.4.2. OPPORTUNITIES OF APPLYING THE CHEMICAL ENVIRONMENT TO THE CONSTRUCTION MANAGEMENT INFORMATION SIMULATION ENVIRONMENT

Both the chemical and construction management information simulation environment consist of certain elements. Tens of chemical elements have been identified to this point, a number which can be increased in the future as soon as new elements in nature are

discovered. On the other hand, construction management information simulation elements are defined and can be increased as soon as new approaches or methods are declared. The interaction between chemical elements is responsible for the electron flow in nature and creating new aggregates or substances from that, just as the interaction between simulation elements during simulation run is responsible for information flow in the model. The types of chemical elements are always sending, receiving, or sharing electrons during their interaction with other elements. The same pattern of elements classes can be recognized in simulation elements. They are also always sending, receiving, or sharing information during a simulation run. This can lead us to define a systematic pattern of interaction processes between simulation elements during a simulation run. A well defined product can be known from the interaction of any pair or group of chemical elements. The same manner can be predicted for the interaction of simulation elements. Based on the types of chemical elements that are interacting together, the type of bond that will occur between these elements can be expected. The bond or relationship could be either ionic (sending and receiving information) or covalent (sharing information).

In chemical interaction, the valence electron(s) is (are) responsible for the interaction process. The same pattern can be recognized in a simulation environment. Some main attributes are responsible for the interaction process between the elements. Some main assumptions are shown in the map key (Figure 5.7) and are described in a previous paper as follows:

1) The active role of element X, which represents the main information interaction duty of element X towards element Y by the transfer of new attribute(s) value

from element X to element Y, is simulated to transfer the electron(s) in a chemical environment. In this role element X is sending data to element Y.

2) The passive role of element X, which represents the main information interaction duty of element Z towards element X by the transfer of new attribute(s) value from element Z to element X, is simulated to transfer the electron(s) in a chemical environment. In this role element X is receiving data from element Z.

3) The attributes of element X are simulated as Electrons in a chemical environment. The value of these attributes is updated during a simulation run, but information transfers only between the elements that have relationships (bonds).

4) The active and passive roles interact in the relationships between the elements. These relationships are binary, and can be either covalent or ionic as in chemical environment. A covalent relationship means that both of the elements that share this relationship can share this role and accordingly attribute(s) value transfers through this role with more than one element. An ionic relationship means that both of the elements that share this relationship can not share this role and accordingly attribute(s) value transfers through this role with any other element.

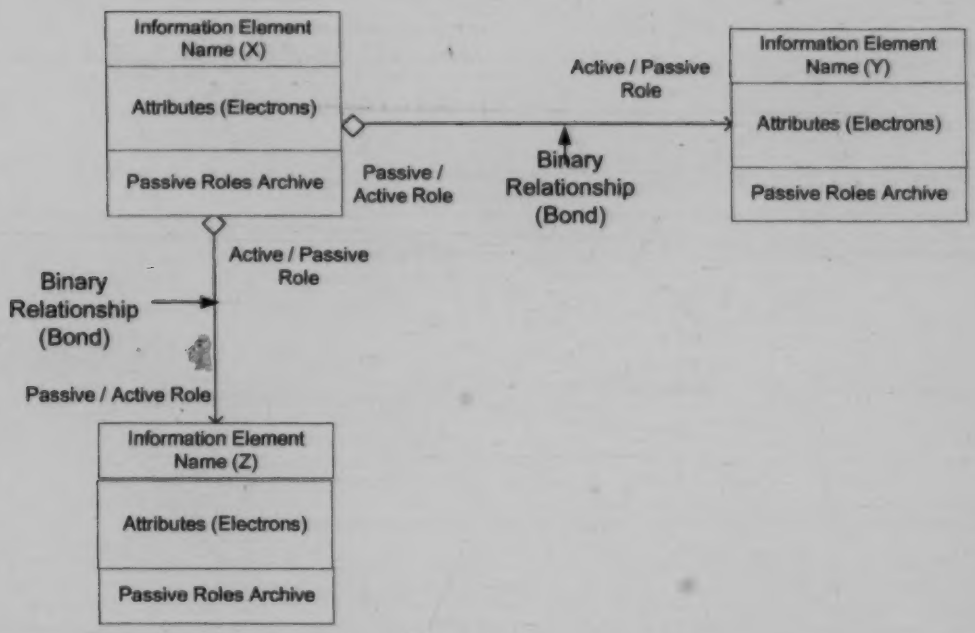



**Figure 5.7 : Information Elements Maps Key using Chemical Similarity**

The proposed conceptual model that can enhance the capabilities of IICSS is summarized in the following five steps:

**Step 1**: Chemical classes of simulation elements

Table 5.1 describes the proposed classes of the construction management information simulation elements of IICSS at abstract level 4 as metallic, transition, or non-metallic elements. The same concept can be extended to the other abstract levels as well as to other elements not defined here. Metallic elements are the elements that are responsible for sending information to other non-metallic or transition elements. Their active roles are executed through ionic relationships only. Non-metallic elements are the elements responsible for receiving information from the metallic or transition elements or sharing

information with other non-metallic or transition elements. Their active roles are executed through covalent relationships only. Transition elements can either work as metallic or non-metallic elements. Their active roles are executed through either ionic or covalent relationships. Table 5.1 illustrates the twelve simulation elements at abstract level 4 as described in chapter five. The same methodology can be applied to the other abstract levels. The table can be described as **the Periodic Table of Construction Management Information Simulation Elements**.

**Table 5-1 : Chemical classes of Construction Management Information Simulation Elements**

| Metallic Elements | Transition Elements | Non-Metallic Elements |
|---|---|---|
| Resource | Actor | Component |
| Facility Component | Actor Use | Task |
| | Resource Use | Milestone |
| | Facility Component Use | Result |
| | Management Object | Document |

**Step 2**: Chemical interaction capabilities of simulation elements

According to the previous proposed classes of simulation elements, Table 5.2 shows the opportunity of information interaction between these elements during a simulation run. The metallic elements will not be able to interact together, while other types of elements can interact and exchange information during a simulation run.

**Table 5-2 : Chemical Interaction Capabilities of Construction Management Simulation Elements**

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | ■ | ■ | X | ■ | X | X | X | X | X | X | X | ■ |
| Actor | ■ | ■ | ■ | X | X | X | X | X | X | X | X | X |
| Actor Use | X | ■ | X | ■ | X | X | X | X | ■ | X | X | ■ |
| Task | ■ | X | X | ■ | ■ | ■ | X | X | ■ | X | ■ | ■ |
| Milestone | X | X | X | ■ | X | X | X | X | X | X | X | ■ |
| Result | X | X | X | ■ | X | X | ■ | ■ | X | X | X | X |
| Document | X | X | X | X | X | ■ | ■ | X | X | X | X | ■ |
| Resource | X | X | X | X | X | X | X | X | ■ | X | X | X |
| Resource Use | X | X | ■ | ■ | X | X | X | ■ | X | X | X | ■ |
| Facility Comp | X | X | X | X | X | X | X | X | X | X | ■ | X |
| Facility Comp. Use | X | X | X | ■ | X | X | X | X | X | ■ | X | ■ |
| Management Object | ■ | X | X | X | X | X | ■ | X | X | X | X | ■ |

X No opportunity for information transfer between these elements during simulation run

■ Opportunity for information transfer between these elements during simulation run

**Step 3**: Chemical equations and outputs of simulation elements interactions

This step illustrates proposed systematic interactions between the elements during a simulation run. These interaction equations are noticeable among these elements, which means these elements can interact together and produce these outputs based on their previous opportunities of interaction as described in table 5.2.Any developed simulation system should at least have these elements produce their intended outputs. Figure 5.8 illustrates a summary of these interaction equations.

- Task + Task = Activity
- Component + Component = Product
- Component + Component + Task + Task = Product + Activity
- Component + Component + Task + Task + Actor + Actor Use = Product + Activity +Actor Group
- Component + Component + Task + Task + Milestone = Product + Activity + Product Milestone
- Component + Component + Task + Task + Result = Product + Activity + Resource Group + Product Document
- Component + Component + Task + Task + Document = Product + Activity + Product Document
- Component + Component + Task + Task + Resource + Resource Use = Product + Activity +Resource Group
- Component + Component + Task + Task + Facility Comp. + Facility Comp. Use = Product + Activity + Facility Comp. Group
- Component + Component + Task + Task + Manag. Object = Product + Activity + Product Manag. Object
- Component + Component + Task + Task + Manag. Object + Actor + Actor Use = Product + Activity + Product Manag. Object + Actor Group
- Component + Component + Task + Task + Manag. Object + Resource + Resource Use = Product + Activity + Product Manag. Object + Resource Group
- Component + Component + Task + Task + Manag. Object + Facility Comp. + Facility Comp. Use = Product + Activity + Product Manag. Object + Facility Comp. Group
- Component + Component + Task + Task + Manag. Object + Milestone = Product + Activity + Product Manag. Object + Product Milestone

**Figure 5.8 : Description of information interaction equations of simulation elements**

The outputs of these equations are elements at abstract level 3 as shown in chapter five. The existence of two instances of any element at the left hand side of the equation means at least two instances of this element should exist to activate this interaction, while one instance means that one instance of this element can run this interaction. All of these equations can be applied depending on the user's objectives for the simulation model. These equations can be used as add-in tools to existing automated approaches such as one described by Ali (2002).

**Step 4**: Types of chemical relationships (bonds) between simulation elements

Table 5.3 describes the expected types of relationships (bonds) between these elements during a simulation run. They can either be covalent or ionic, as described before. The type of relationship will define the opportunity of sharing data (attribute values or electrons) with more than one instance of an element during a simulation run or only between two elements at one time. This table is based on the result of table 5.2 that describes if there is any relationship between these elements or not.

**Step 5**: Types of valence information between simulation elements

Table 5.4 describes the information types (valence information) transferred between various information simulation elements at abstract level 4. The table describes the systematic information transfer pattern based on the potential information relationships table 5.2 and the types of the relationship (table 5.3) between these elements.

**Table 5-3 : Types of Chemical Relationships between Construction Management Simulation Elements**

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | C | C | | C | | | | | | | | I |
| Actor | C | C | I | | | | | | | | | |
| Actor Use | | I | | I | | | | | C | | | C |
| Task | C | | | C | C | C | | | I | | I | C |
| Milestone | | | | C | | | | | | | | C |
| Result | | | | C | | | C | C | | | | |
| Document | | | | | | C | C | | | | | C |
| Resource | | | | | | | | | I | | | |
| Resource Use | | | C | I | | | | I | | | | C |
| Facility Comp. | | | | | | | | | | | I | |
| Facility Comp. Use | | | | I | | | | | | I | | C |
| Management Object | I | | | | | | C | | | | | C |

**I** Ionic relationship (information are transferred between elements)

**C** Covalent relationship (information are shared between elements)

**Table 5-4 : Types of Valence information between Construction Management Information Simulation Elements**

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Component** | ID, Start, Finish, Availability | ID, Type of Respon-sibility | | ID, PV, SPI, Original Budget (hr), Trends (hr), Budget Shift (hr), ChangeOrder (hr), Original Budget ($), Trends ($), Budget Shift ($), ChangeOrder ($), EV($), EV(hr), CPI, HPI, % Duration Complete, WBSCode | | | | | | | | ID, Cost, Availability, % Comp., Start, Finish, WBS Code |
| **Actor** | ID, Type of Responsibili-ty | ID, Type of Perfor-mance | ID, Time Calcu lation, Start, Finish | | | | | | | | | |
| **Actor Use** | | ID, Time Calculat -ion, Start, Finish | | ID, Cost Calculation, Time Calculation, Start, Finish | | | | | ID, Time Calculati-on, Cost Calculati-on | | | ID, Cost Calculation, Time Calcul-ation, Start, Finish |

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task | ID, PV, SPI, Original Budget (hr), Trends (hr), Budget Shift (hr), ChangeOrder (hr), Original Budget ($), Trends ($), Budget Shift ($), ChangeOrder ($), EV($), EV(hr), CPI, HPI, % Duration Complete, WBSCode | | | ID, Start , Finish | ID, Finish | Start , Finish | | | ID, Cost Calculation, Time Calculation, Start, Finish | | ID, Cost Calculation, Time Calculation, Start, Finish | ID, PV, SPI, Original Budget (hr), Trends (hr), Budget Shift (hr), ChangeOrder (hr), Orig. Budget ($), Trends ($), Budget Shift ($), ChangeOrder ($), EV($), EV(hr), CPI, HPI, % Duration Complete, WBS Code |
| Milestone | | | | ID, Finish | | | | | | | | ID, Name, Status |
| Result | | | | Start , Finish | | | Planned Available Time, Type of Control, ID | Planned Available Time, Type of Control, ID | | | | |

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Document | | | | | | Planned Available Time, Type of Control, ID | ID, Type, Description, Creation Time, Last Revision Time | | | | | ATD($), ATD(hr), EAC($), EAC(hr), FTEs ATD, FTEs EAC, % Complete, PF(hr), PF($), Rework(hr), EAC Rework(hr), Qualitative Risk Score, Quality Control Inspection, Unit Rate ATD($/hr), Unit Rate EAC($/hr) |
| Resource | | | | | | | | | ID, Availability, Resource Consumption, Available Quantity | | | |

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resource Use | | | ID, Time Cal., Cost Cal. | ID, Cost Calculation, Time Calculation, Start, Finish | | | | ID, Availability, Resource Consumption, Available Quantity | | | | ID, Cost Calculation, Time Calculation, Start, Finish |
| Facility Comp | | | | | | | | | | ID, Availa-bility, Resource Consu-mption, Avail-able Quant-ity | | |
| Facility Comp. Use | | | | ID, Cost Calculation, Time Calculation, Start, Finish | | | | | | ID, Availa-bility, Resour-ce Cons-umption, Available Quanti-ty | | ID, Cost Calculation, Time Calcul-ation, Start, Finish |

| Simulation Element | Component | Actor | Actor Use | Task | Milestone | Result | Document | Resource | Resource Use | Facility Comp. | Facility Comp. Use | Management Object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Management Object | ATD($), ATD(hr), EAC($), EAC(hr), FTEs ATD, FTEs EAC, % Complete, PF(hr), PF($), Rework(hr), EAC Rework(hr), Qualitative Risk Score, Quality Control Inspection, Unit Rate ATD($/hr), Unit Rate EAC($/hr) | | | | | | ATD($), ATD(hr), EAC($), EAC(hr), FTEs ATD, FTEs EAC, % Complete, PF(hr), PF($), Rework (hr), EAC Rework (hr),Quali -tative Risk Score, Quality Control Inspectio n, Unit Rate ATD($/hr ), Unit Rate EAC($/hr ) | | | | | ATD($), ATD(hr), EAC($), EAC(hr), FTEs ATD, FTEs EAC, % Complete, PF(hr), PF($), Rework(hr), EAC Rework(hr),Q ualitative Risk Score, Quality Control Inspection, Unit Rate ATD($/hr) / EAC($/hr) |

## 5.5. PROTOTYPE MODEL

Excel sheet macro & *Simphony* (AbouRizk and Hajjar 1998) were used to illustrate this approach and apply it to an excavation case study. Figure 5.9 shows the Excel model, including the main five steps described for the IICSS approach and running model to approve the methodology. Figure 5.9 illustrates the application of this approach in a simulation environment using *Simphony* for 4 elements, as an example.

**Results and Analysis**

The same *Simphony* template that was developed in chapter 4 has been modified to incorporate the new proposed approach as follows:

1) Adding attribute to all of the simulation template elements in order to distinguish their periodic type as metallic, transition, or non-metallic as shown in step 1.
2) Define the capability of their interaction during a simulation run based on that as described in step 2.
3) Create automated new simulation elements at higher abstract levels based on the pre-defined equations as described in step 3.
4) Apply the type of chemical relationship between these elements as in step 4.
5) Finally define the data transferred between these elements during a simulation run along with the current entities as shown in step 5.

The model is developed under the schedule federate simulation element at level 4 and the output simulation elements of the right-hand side of the equations are reflected in the schedule federate simulation element at level 3. The same application could be applied to

other simulation elements and federates. The developed approach is expected, along with introducing these automated elements in simulation systems, to enable these elements to automatically verify the element type that it can interact with, as well as the type of data that should be transferred between them during simulation run. They can also identify the method through which to interact with each other in the system. Also, the output elements of the interaction between these elements can be automatically produced during simulation run. The new standard anatomy for construction management information elements can be used easily in the future to add new elements to it with the same criteria, which increase the interoperability of the simulation environment. Table 5.1 illustrates the difference between the developing of the same model using IICSS and traditional simulation techniques, using a common template in *Simphony*. The advantages of using this new approach are described in detail. This approach is an initiation for developing a standard library for construction management simulation systems. This method can be used as a basis for an automated approach to create new elements during a simulation run.

**Table 5-5 : Comparison of Developing the Model using Traditional and New Technique**

| Item | Traditional Method | New Method |
|---|---|---|
| **Pre-knowledge of Simulation** | Required | Not required |
| **Flexibility to add New Elements during Simulation Run** | Not flexible | Flexible |
| **Generic Information Pattern** | Not achieved | Achieved |
| **Automation** | Not existed | Achieved |
| **Model Complexity** | High. There is a need to add all elements at all abstract levels before simulation run. | Very limited. No need to add elements at higher abstract levels. They will be created during simulation run. |

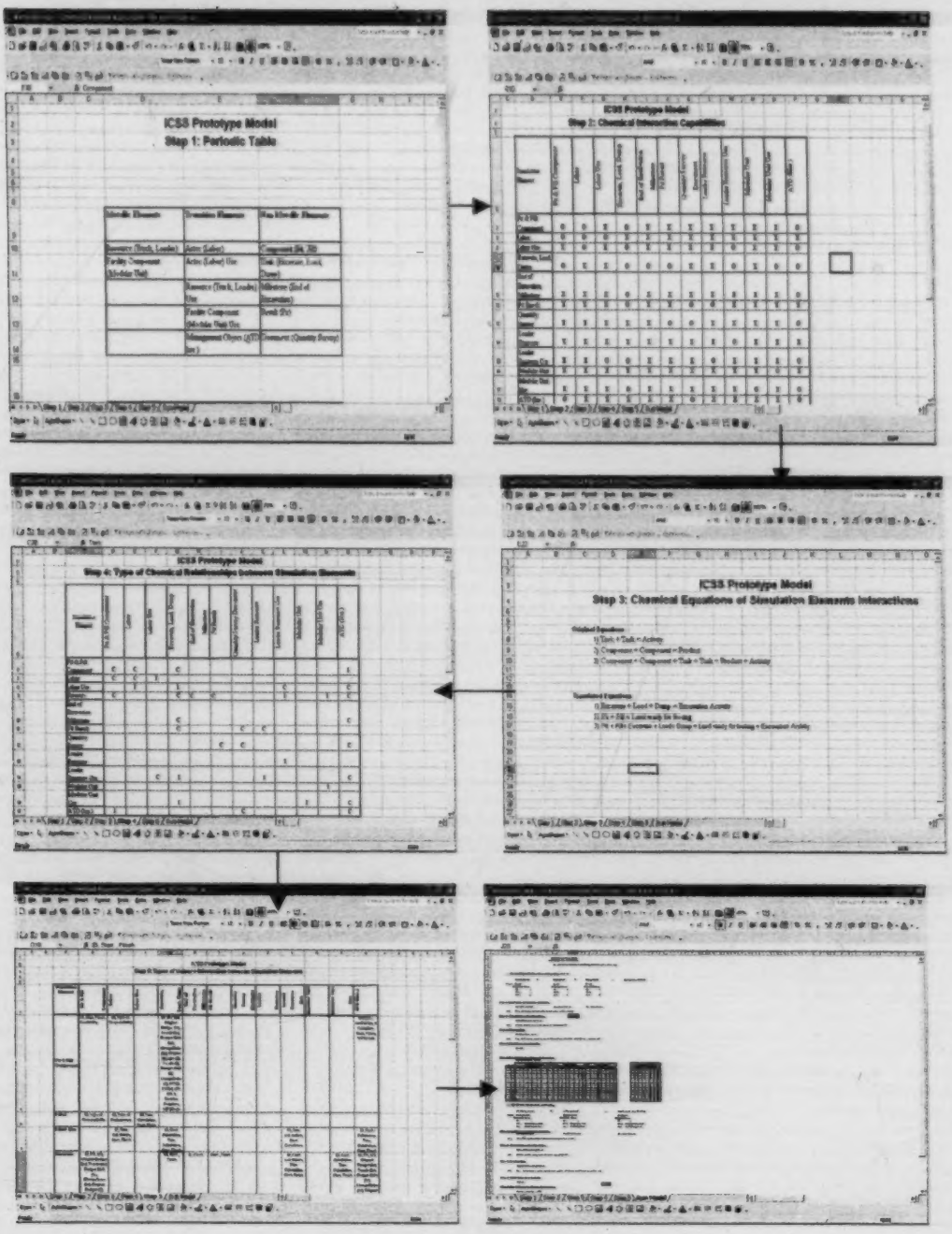

ICSS Prototype Model
Step 1: Periodic Table
ICSS Prototype Model
Step 3: Chemical Equations of Simulation Elements Interactions

**Figure 5.9 : Prototype Excel model**

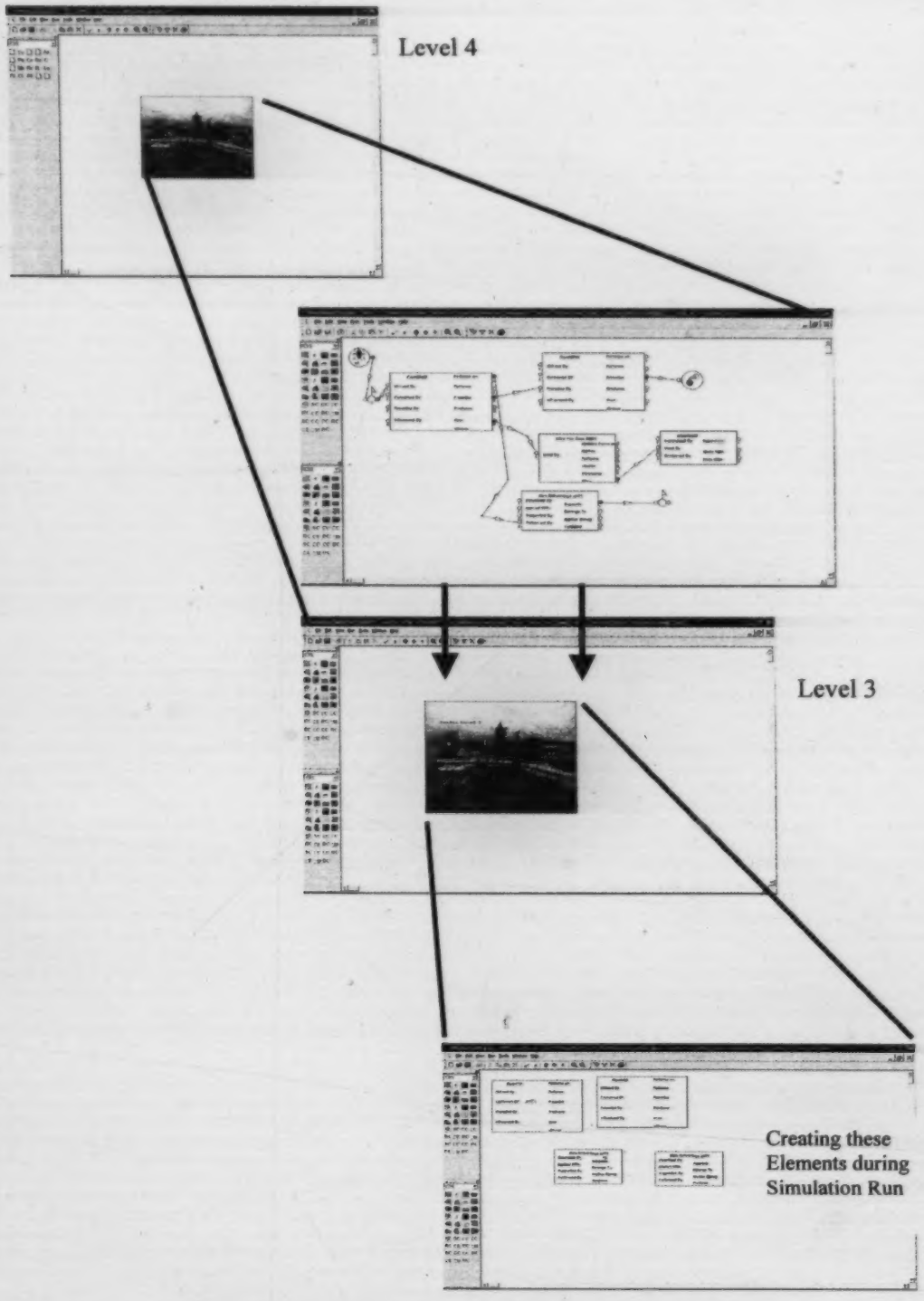



**Figure 5.10 : Prototype model application in Simphony**

## 5.6. POTENTIAL FUTURE WORK

According to the work that has been analyzed and discussed in the last sections, some major areas that potentially could be investigated in the future as a continuation for this research are as follows:

1) Extend this research to cover all of the information elements (concepts) developed in a detailed Ontology, such as HIONTO, or the elements defined in information models, such as IFC2X or OCCS.
2) Discover other areas of chemistry principles and theories that can affect this similarity, such as ELECTRONEGATIVITY, MOLECULAR BONDS, and SCALAR COUPLING.
3) The work could extend to cover other construction management processes, such as quality control, document control, risk management, change management, and rework management.
4) Refine the available services of the existing *Simphony* program to enable the full application of this similarity.
5) The applicability of this approach to be applied on a generic information model, such as IFC2X.
6) Developing a standard periodic table for all the construction industry elements that are automated enough to use this approach add a high value in increasing the flexibility of construction application software integration.

## 5.7. SUMMARY

A chemical-oriented simulation methodology provides an alternative way to simulate construction management processes, as it looks at the structure, relations, interactions, and types of elements in the real world, rather than just at the simulation execution process itself. This will significantly enhance the way in which simulation models will design, build, and operate. The presented approach is aimed to provide an integrated environment that will allow end-users to experience simulation without extensive knowledge of simulation or large amounts of data entry. Although the outline focuses mainly on some elements at only one abstract level of information, the approach developed here can be applied easily and extended to other elements and abstract levels in the same way. The proposed structure provides a useful framework for managing the construction process of any simulation model and the retrieval of information for all construction management processes as well. However, more research and enhanced simulation environment, including several other services are required to provide better functionality and accessibility of the information in the simulation system.

## 5.8. REFERENCES


- AbouRizk, S.M. and Hajjar, D. (1998). "A framework for applying simulation in construction." Can. J. Civil. Engrg. CSCE, 25, 604-617.
- Chang, D. (1987). "RESQUE." PhD thesis, Univ. of Michigan, Ann Arbor, Mich.

- Halpin, D.W. (1973). "An investigation of the use of simulation networks for modelling construction operations." Ph.D. thesis, Univ. of Illinois at Urbana-Champaign, Ill.
- Ioannou, P.G. (1989). "UM-CYCLONE user's guide." Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Mich.
- Masterton, W.L., and Hurley, C.N. (1993). "Chemistry Principles and Reactions." Saunders College Publishing.
- Paulson, B.C. (1978). "Interactive graphics for simulating construction operations." J. Constr. Div., ASCE, 104(1), 69-76.
- Perucci, R.H., and Harwood, W.S. (1997). "General Chemistry Principles and Modern Applications." Prentice Hall, New Jersey.
- Sawhney, A., and AbouRizk, S.M. (1995). "Simulation based planning method for construction project." J. Constr. Engrg. and Mgmt. ASCE, 121(3), 297-303.
- Shi, J., and AbouRizk, S.M. (1997). "Resource-Based Modeling for Construction Simulation." J. Constr. Engrg. and Mgmt. ASCE, 123(1), 26-33.
- Zumdahl, S.S., and Zumdahl, S.A. (2000). "Chemistry." Houghton Mifflin Company.

# CHAPTER 6. APPENDIX - RELATED RESEARCH WORK

## 6.1. ABSTRACT

Two main studies have been conducted to enforce the proposed IICSS approach. A detailed survey of the research developed in the last decade for Information Technology (IT) applications in the construction management field has been completed. Image processing techniques were used to develop a new automated data acquisition system for use in construction. The survey has been used as an analysis tool to review literature and define the potential of further research areas for IT applications within construction. The results of the analysis prove need for simulation and information models to cover more construction management areas. The data acquisition system enhanced the method of data collection that is necessary for running any simulation model and also increases its reliability. This new approach has limitations in only being applied for certain types of construction processes, such as excavation, foundation, earthwork, and paving. But, the system could increase the acceptance of the simulation model in the industry by using the input data and running the simulation model at the same time as the construction process. The accuracy and cost effectiveness of this approach are another advantage for developing it. The integrated construction simulation system should include powerful input data to strengthen its pre-run phase. This chapter introduces these two related research work areas: survey of the IT applications in construction, and a new data acquisition system.

## 6.2. SURVEY OF INFORMATION TECHNOLOGY APPLICATIONS IN CONSTRUCTION

### 6.2.1. ABSTRACT

Information Technology in Construction (ITC) has become a key topic in the last two decades, gaining wide acceptance and is being implemented in the construction research domains as a tool to assist decision-makers. Defining the trends of ITC application over the years are essential to provide researchers with a background of what has been done, to shade the light on what direction to be taken in the future application of ITC. This paper presents a holistic view of ITC applications in construction during the last ten years. It describes the survey results in the application of information technology in construction, which have been published in twelve scientific journals between 1992 and 2001. This paper focuses primarily on nine ITC tools. It describes their integration, and their use in forty-three construction applications.

### 6.2.2. INTRODUCTION

Construction is a collaborative work involving a multi-disciplinary team, which includes the owners, architects, engineers, consultants, contractors, etc. At present, a communication problem between the team members and the need for decision-making under uncertain conditions are often the causes for project delay, cost increase, and project quality defects (Sun and Aouad 1999). Despite the rapid improvement in software and hardware, the problems in construction, which were identified ten years ago, are still

the same, unchanged and as difficult to solve as before. In 1995, the UK Department of Environment strategy for construction clearly identified the lack of investments in IT as a major obstacle to the effective adoption and application of this technology in the sector (Andersen, et al. 2000). The gap between IT investment plans and the manager's own understanding of the construction business and the nature of the industry, also contributed to the lack of IT involvement in the construction sector compared to other business sectors. In addition the construction industry has been required to reduce profit margins, leaving little room for investment, especially in such an environment as rapidly changing as IT (Andersen, et al. 2000).

The methodological issues of ITC have not been widely discussed in the literature (Bjoerk 1999). Aouad et al. (1996) surveyed 16 main topics related to ITC published in scientific journals in a study to establish the need for prioritizing ITC topics for the future.

He found that CAD, AI, integration, and databases were extensively covered during the period of his study from 1990 to 1994, which focused on scientific journals published in the United Kingdom. The study did not differentiate between the tools used in ITC, and those areas that can be elucidated by these tools. He expected the priority in future research will be in the fields of communications/networking, CAD, and computer-aided planning.

This paper, however, describes the results of a survey for the period of 1992 to 2001, focusing on an analysis of the contributions of nine ITC tools to the construction research sector. It relates their contributions to 43 construction areas and highlights the integration of these tools into the industry. The survey conducted and presented in this paper shades

the light on the future trends in ITC research. Continuous research in this trend is essential to provide a holistic view of ITC related research in general and also to clearly view its overall significance.

### 6.2.3. RESEARCH FRAMEWORK

This research provides information on the results of a survey of ITC application into the construction sector. This paper reviews papers published in 12 scientific journals (listed in Table 2) for the period of 1992 to 2001, focusing mainly on the tools and application areas. The initial work on the paper consisted of reviewing over 30 scientific journals, then limiting the scope to the 12 related ITC scientific journals only. The principle method used in determining which scientific journals would fall within this scope follows the process classified by Li and Davies (1998). The nine ITC tools analysed in this paper are: 3D rendering, simulation, Fuzzy Set theory (FS), Neural Networks (NN), Expert Systems (ES), Database Systems (DB), Data Modelling (DM), Geographic Information Systems (GIS), and Virtual Reality (VR). The following six analysis approaches and criteria have been used to analyze the collected data for the period of the study:

- Based on the frequency of papers published using each tool
- Based on the frequency of papers published for each construction area using all of these tools
- Based on the frequency of papers published for each construction area within each one of these tools
- Based on the frequency of papers published for each of the tools within each phase of the construction project

- Based on the percentage of generic and/or non-generic papers published on the topic
- Based on the integration ability of each pair of the 9 tools.

Papers published have been classified according to the following five criteria:

1) The area of construction (forty-three areas)
2) The phase of the construction project (pre-design, design, construction, and operation)
3) The applied ITC tool
4) The year of publication
5) Its coverage (generic or non-generic).

The analysis of the study presented in this paper has been designed to achieve the specific objectives of this research, which can be explained in the following three logical sequence steps: To identify the awareness of information technology applications in construction within the research sector; To explore the tools of ITC, and areas within construction that can be enhanced by this research; and To provide solutions and highlight potentials for new opportunities in the ITC research area.

### 6.2.4. INFORMATION TECHNOLOGY IN CONSTRUCTION (ITC)

Information Technology, by definition, is a collective reference to the integration of computing technology and information processing (Long and Long, 1997). IT is not a single technology but a wide range of technical approaches to a variety of problems (Froese 1999). Construction process, as per this study, includes the whole life cycle of the

project, including pre-design, design, construction, and operation and maintenance. In particular, it is important to stress the inclusion of operation and maintenance since a significant part of the information, used during these stages, originates during design and construction. Therefore, ITC can be defined as the application of decision-support tools, by which uses electronic machines and programs for processing, storage, analysis, control, transfer, and presentation of construction information data during the whole life cycle of a construction project.

For the last two decades the construction industry has experienced a surge in developing and applying information technologies. Researchers have experimented with innovative ways of using ITC to improve the efficiency and productivity of the construction industry. The first reported ITC endeavor consisted of the basic concepts found in the Program Evaluation Review Technique (PERT), and was developed by the US Navy Special Projects Office in an effort to create a management method to administer contractors for the design, the construction, and testing of the POLARIS submarine and missile systems. In August 1959, a computer program was developed to process the PERT networks on an IBM Corporation 704 mainframe. After nearly 26 years, in 1986, there were about a thousand vendors of ITC software. The first two application areas for ITC were planning and scheduling. Prior to the advent of network techniques and "modern project management" in the late 1950s (Fondahl 1987), construction planning and scheduling was based mainly on the intuition and expertise of experienced site personnel. The first generation of project planning was superseded by a second generation of network-based, computer-assisted techniques (Froese 1992). In the early 1970s, the third generation of project planning appeared which was also developed in

research institutions (Paulson 1972 and 1973). In the 1980s this third generation began a foundation of a wealth of micro-computer-based project planning systems (Fersko Weiss 1989). In general the programs for ITC are functionally very much alike and have not changed dramatically since the introduction of PERT/Cost (Badger 1987).

ITC has been mainly applied for planning and scheduling applications up to the late 1980s. In the latter part of that decade most research in the field of ITC focused on CAD integration, because it was considered the first and most crucial stage towards computerization in construction (Cutting-Decelle et al. 1997). In recent years research has focused on the development of these applications as required by the industry to support electronic document management system. As a result, there has been rapid expansion in the development of IT applications available to all construction professionals. For example, in 1997 alone, there were about 1700 packages for ITC (CICA 1997).

The importance of ITC has been described by a number of researchers, with the aim of highlighting the benefits of information technology to the construction industry (Betts 1992, Brandon 1993, Ibbs 1987, Miyatake and Kangari 1993, Nam and Tatum 1992, O'Brien 1991, Teicholz and Fisher 1994, Tucker et al. 1994, Oliver 1994, KPMG 1993, and Aouad et al. 1996). This paper describes the results of the survey and the analysis of nine tools of ITC, which are categorized based on their use in the forty-three areas of construction application listed in Table (6.1). The matrix is a point of view of the authors for the areas that have been covered or not covered in the publications in the selected twelve scientific journals listed in Table (2.2).

## 6.2.5. ANALYSIS OF ITC APPLICATIONS

The ITC scientific journals listed in Table (6.2) have the sources of data to be used in this report and include papers published during the last ten years (between January 1992 and December 2001). Table (6.2) shows also the degree (D) to which any of these tools have been reported. It was calculated according to the percentage of number (n) of published papers using any of the nine tools to the total number (N) of published papers for each journal during the whole period of the study satisfying equation (2.1):

$D = n / N$ ..... (2.1)

Where : **H** is Highly discussed, when D >70 %.

**M** is Moderately discussed, when 70% > D > 30%

**W** is Weakly discussed, when D > 30%

**Table 6-1 : Matrix for the 43 areas of application for the selected 9 ITC tools**

| | 3D | Sim | DB | Data Model | ES | NN | FS | GIS | VR |
|---|---|---|---|---|---|---|---|---|---|
| Scheduling | • | • | • | • | • | • | • | • | • |
| Estimating | • | • | • | • | • | • | • | • | • |
| Cost control | • | | • | • | | • | | • | • |
| Change-order tracking | • | | • | • | | • | | • | • |
| Materials tracking | • | | • | • | • | • | • | • | • |
| Project budgeting | | • | • | • | | • | | • | |
| Resource management | • | • | • | • | • | • | • | • | • |
| Equipment management | • | • | • | • | • | • | • | • | • |
| Inventory control | • | • | • | • | • | • | • | • | • |
| Purchasing/supplier | • | | • | • | • | • | • | • | • |
| Financial planning | | • | • | • | | • | | • | • |
| Engineering and | • | | • | • | | | | • | • |
| Computer-aided design and drafting (CADD) | • | • | • | • | | | | • | • |
| Quality management | • | • | • | • | • | • | • | • | • |
| Productivity management | • | • | • | • | • | • | • | | • |
| Risk management | • | • | • | • | • | • | • | • | • |
| Lean construction | • | • | • | • | • | • | • | • | • |
| Planning | • | • | • | • | • | • | • | • | • |
| System Integration | • | • | • | • | | | • | • | • |
| Safety management | • | • | • | • | • | • | • | • | • |
| Bidding& contracting | • | • | • | • | • | • | • | • | • |
| Construction | • | • | • | • | • | • | • | • | • |
| Site planning | • | • | • | • | | • | • | • | • |
| Project Selection (owner's point of view) | | • | • | • | • | • | • | • | • |
| Rework | • | • | • | • | • | • | • | • | • |
| Delay management | • | • | • | • | • | • | • | • | • |
| Technology acceptability | | | • | • | • | • | • | | |
| Construct ability | • | • | • | • | • | • | • | • | • |
| Time control | • | • | • | • | • | • | • | • | • |
| Client Satisfaction | • | • | • | • | • | | • | • | • |
| Contractors/subcontracto | • | • | • | • | • | • | • | • | |
| Value engineering | • | • | • | • | • | • | • | • | • |
| Dispute management | • | • | • | • | • | • | • | • | • |
| Claim management | • | • | • | • | • | • | • | • | • |
| Performance evaluation | • | • | • | • | • | • | • | • | • |
| Partnering management | • | • | • | • | | | | | • |
| Environmental management | • | • | • | • | • | • | • | • | • |
| Human performance | | • | • | • | • | • | • | | |
| Daily site reporting | • | • | • | • | | | | • | • |
| Site investigation | • | • | • | • | • | • | • | • | • |
| Maintenance management | • | • | • | • | • | • | • | • | • |
| Labor management | • | • | • | • | • | • | • | | • |
| Data acquisition | • | | • | • | • | | • | • | • |

• Covered
Not Covered

**Table 6-2 : Matrix for the 9 ITC tools applications published in the 12 studied scientific journals**

| | 3D | Simulation | Database | Data Model | ES | NN | FS | GIS | VR |
|---|---|---|---|---|---|---|---|---|---|
| Journal of Computing in civil Engineering | M | H | M | H | M | W | W | N | W |
| Journal of Construction Engineering and Management | M | H | W | M | M | M | N | W | N |
| Automation in Construction | W | W | W | H | W | W | W | W | W |
| Canadian Journal of Civil Engineering | H | M | M | H | W | W | M | N | N |
| Computer Integrated Design and Construction (CIDAC) | N | M | M | H | W | N | W | W | H |
| Computer-Aided Civil and Infrastructure Engineering (previously: Microcomputers in Civil Engineering) | M | M | H | H | W | W | M | N | W |
| Journal of Infrastructure Systems | N | N | N | N | H | N | N | N | N |
| Electronic Journal of Information Technology in Construction (ITcon) | M | N | H | H | N | N | N | N | M |
| Construction Management and Economics | N | H | W | W | M | W | H | N | N |
| Engineering Construction and Architectural Management | M | M | W | H | N | H | M | N | N |
| Fuzzy set and system | N | N | N | N | N | N | H | N | N |
| International Journal of Construction information Technology | N | N | N | N | N | N | N | N | N |

| | |
|---|---|
| H | Highly Discussed |
| M | Moderately discussed |
| W | Weakly discussed |
| N | Non discussed |

The data collected from the twelve scientific journals was been analyzed based on the following six criteria:

**Criterion 1**: The number of papers published in scientific journals each year during the last ten years using each ITC tool; a sample for year 1994 is shown in Figure (6.1). The percentage of the total number of published papers for each tool during this period of the study has been calculated and displayed in Figure (6.2). The analysis showed that the

simulation, database, and data model applications are the most frequently used tools contributing to 57% of the total 9 tools, during the period of the study. It also showed that there was a drop in utilization of the simulation application between 1997 and 1999; during the same period, data model utilization was increasing dramatically. The rate of FS application has gradually increased over the last five years of the study, while application of NN has suffered from fluctuation during the entire period of the study. At the same time, the use of ES decreased gradually during the period of the study, while applications related to DB kept their averages during most of the period of the study except for a short decline in 1995 and again in 1998. GIS and VR are the two main tools that suffered a lack of utilization in ITC application during the period of the study. Although VR application has been used during the last two years of the period of the study, GIS remains obscured.

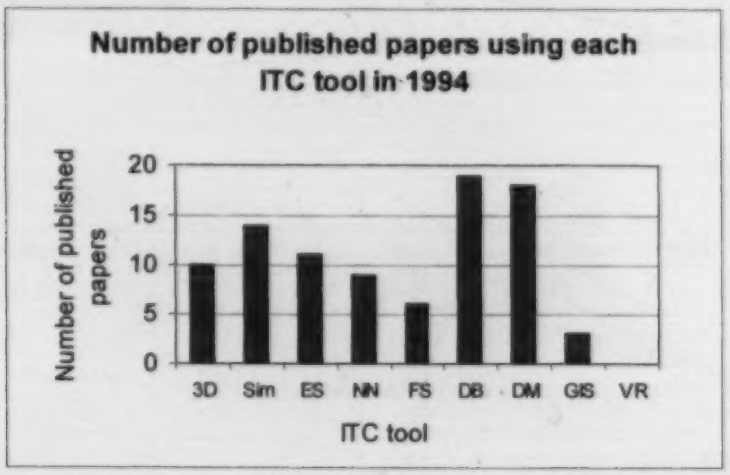



**Figure 6.1 : Number of published papers for each ITC tool in 1994**

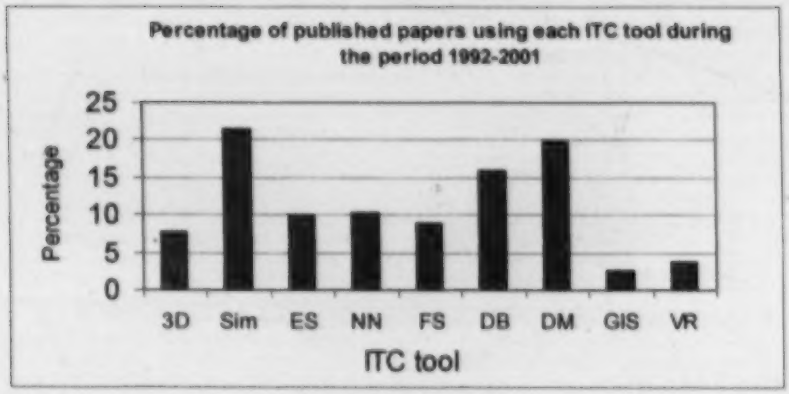



**Figure 6.2 : Percentage of total published papers for each ITC tool during the period 1992-2001**

**Criterion 2:** The total number of papers published in scientific journals over the period of the study for each one of the forty-three areas; a sample for year 2000 is shown in Figure (6.3). This summary of these results showed that the most frequent application of ITC during the period of this study is system integration, followed by the construction processes planning, and then, scheduling. The study also revealed that during the period of the study, ITC tools have been most frequently utilized for the following 13 areas: estimating, cost control, document management, planning, resources management, equipment management, quality management, productivity management, risk management, safety management, bidding and contracting, performance evaluation, and financial planning. Among these 13 areas, productivity management was the most frequently utilized area. Little reference have been made to the following areas: change-order management, inventory control, purchasing/supplier management, engineering and surveying support, computer-aided design and drafting (CADD), lean construction, site planning, project selection (owner point-of-view), rework, delay management,

technology acceptability, time control, client satisfaction, contractors/subcontractors evaluation, value engineering applications, dispute management, partnering management, environmental management system, human performance, daily site reporting management, site investigation, maintenance management, labor management, and data acquisition.

**Criterion 3:** The number of papers published in scientific journals during the period of this study for each ITC tool within each area. Figure (6.4) shows an example of one of these tools, namely the GIS tool. The work has been repeated to cover each one of the forty-three areas. The summary of these results is shown in Table (6.3), which shows every ITC tool, and the frequency of application for each area. Numbers in each cell represents the ascending order for application of each construction area within each tool. For example, the first area utilized within the simulation tool is construction process/modeling, while the ninth area within the same tool is cost control.

**Criterion 4:** The number of papers published in scientific journals during the period of the study for each ITC tool within each of the following four construction project phases: the pre-design phase, design phase, construction phase, and operation phase. Figure (6.5-a) shows an example of this criterion, for each construction phase applying all tools; and Figure (6.5-B) shows each construction phase applying DM tool. A summary of these results showed that the highest frequency of ITC tools utilization was the construction phase, which contributes to more than 50% of the total published papers. The pre-design

phase is the lowest frequent utilization of these tools. A summary of the percentage of application of each tool within each construction phase is shown in Table (6.4).

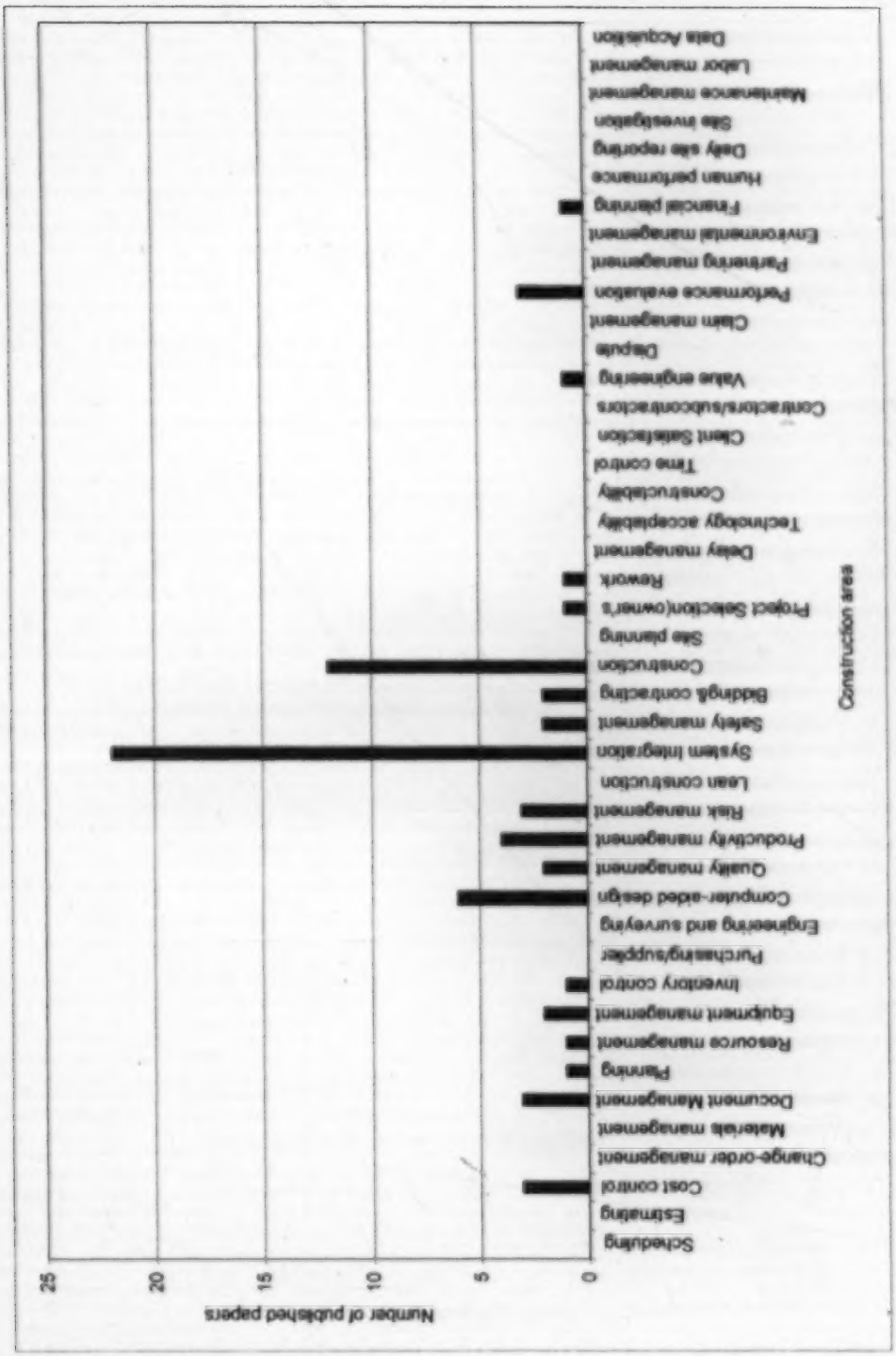



**Figure 6.3 : Number of published papers for each construction area in year 2000**

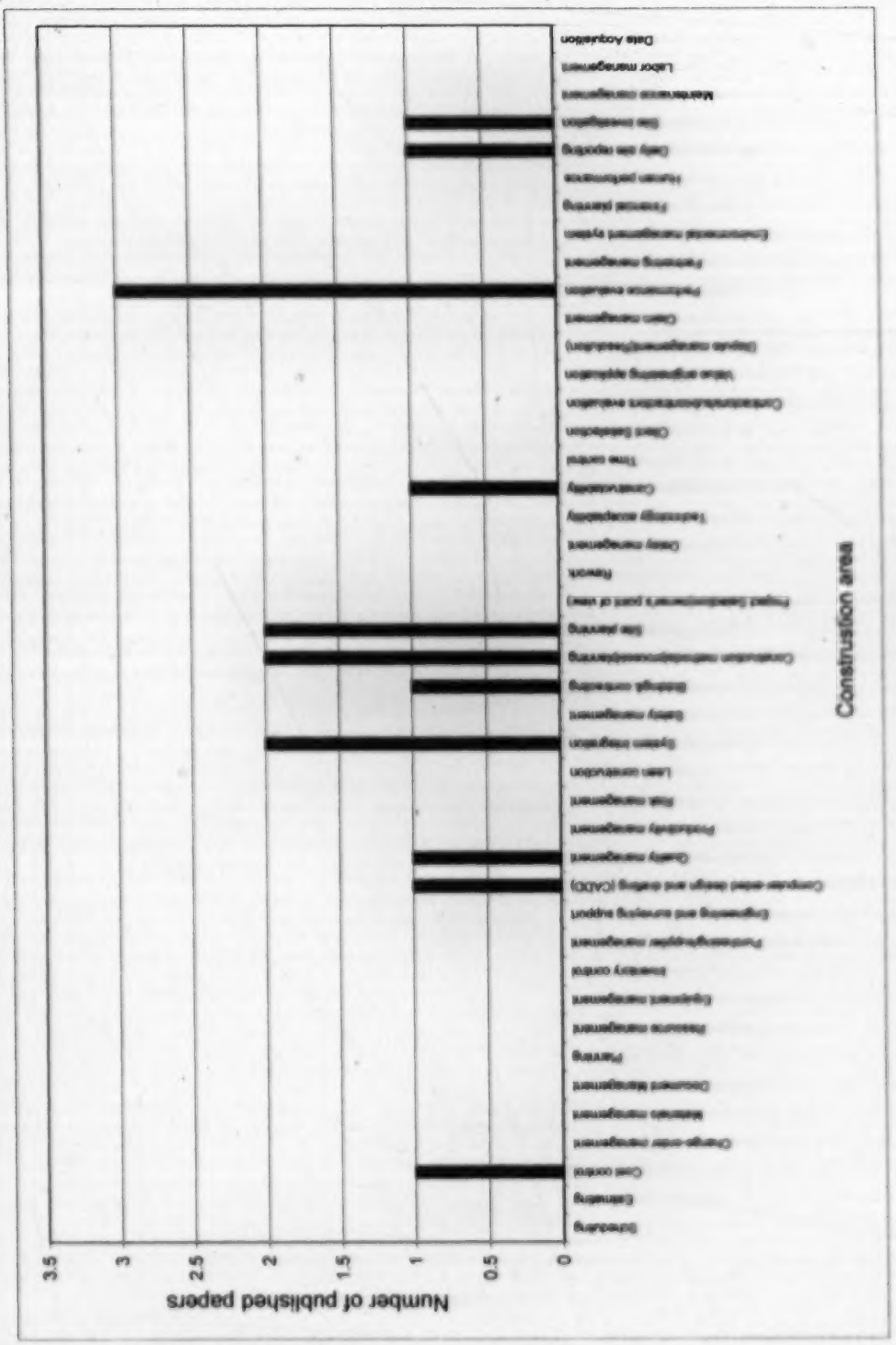


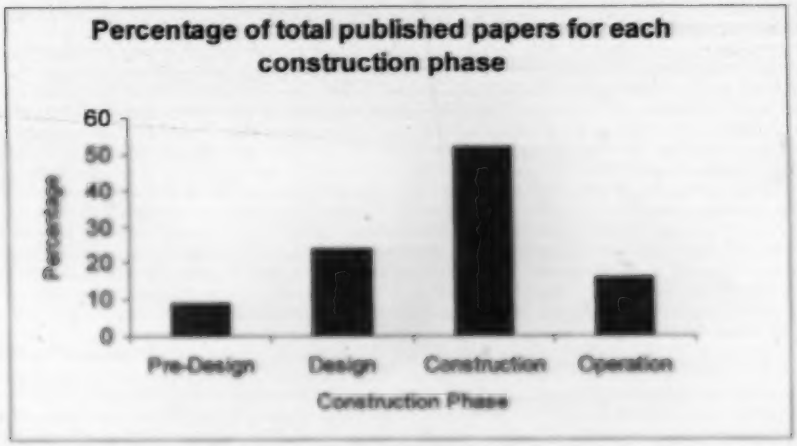

**Figure 6.4 ; Number of published papers for each construction area using GIS**

**Table 6-3 : Sequence of ITC tools applications in ITC areas**

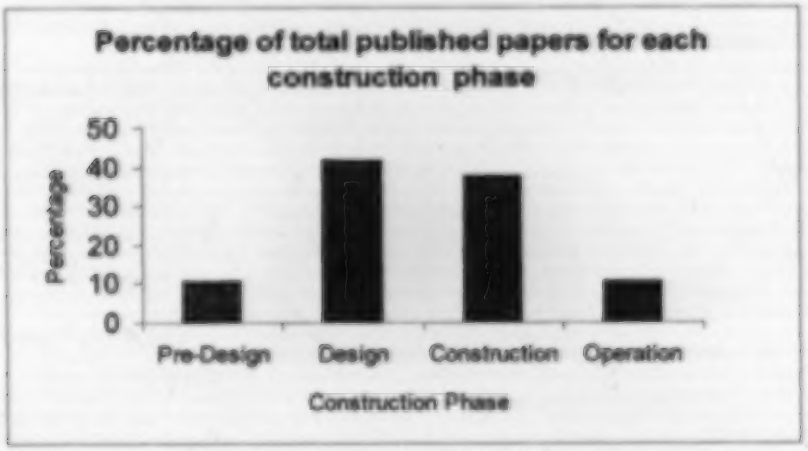
| | 3D | Sim | ES | NN | FS | DB | DM | GIS | VR |
|---|---|---|---|---|---|---|---|---|---|
| Scheduling | 3 | 2 | 5 | 8 | 1 | 3 | 4 | | 3 |
| Site investigation | | | | | | 21 | | 11 | |
| Site Planning | 11 | | 17 | | 17 | | | 4 | |
| Technology Acceptability | | | | 16 | | | | | |
| Time control | | 10 | | | | | | | |
| Bidding & Contracting | | 6 | 7 | 6 | 3 | 10 | 7 | 8 | |
| Change-order Management | | | | | | | | | |
| Claim Management | | | 12 | | | | | | |
| Client Satisfaction | | | | | | | | | |
| Computer-aided design and | 4 | | | | | 8 | 6 | 6 | 2 |
| Constructability | 12 | 16 | 11 | 11 | 8 | 19 | | 9 | 8 |
| Construction | 2 | 1 | 3 | 5 | | 2 | 3 | 3 | 4 |
| Contractors/Subcontractors | | | | | | | | | |
| Cost Control | | 9 | | 3 | 10 | 7 | 8 | 5 | |
| Daily Site Reporting | | | | | 11 | | | 10 | |
| Delay Management | | | 18 | | | 18 | | | |
| Dispute | 13 | 19 | 19 | | 18 | 4 | 2 | | 5 |
| Document Manag. | | | | | | | | | |
| Engineering and surveying | 8 | | | | | | | | |
| Environmental Manag. System | | | | | | | | | |
| Equipment Mang. | | 13 | 8 | 14 | 14 | 12 | 5 | | |
| Estimating | | 8 | 4 | 2 | 5 | 11 | | | |
| Financial Planning | 14 | 14 | 10 | 12 | 9 | | | | |
| Human Performance | | 20 | | | | | | | |
| Information Gathering | | 22 | | | | | | 2 | |
| Integration System | 1 | 10 | 6 | 15 | 15 | 1 | 1 | | 1 |
| Inventory Control | | | 13 | | | | | | |
| Labor Management | | 21 | | | | | | | |
| Lean Construction | | 15 | | | | | | | |
| Maintenance Management | | | | 13 | | | | | |
| Materials Manag. | 5 | 11 | | | | 14 | | | |
| Partnering Manag. | | | | | | | 14 | 1 | |
| Performance Evaluation | 7 | 7 | 1 | 1 | 2 | 6 | | 1 | |
| Planning | 6 | 12 | 2 | | 12 | 5 | 10 | | 6 |
| Productivity Management | | 3 | 9 | 4 | 6 | 9 | 9 | | |
| Project Selection(Owner) | | | | | 16 | | | | |
| Purchasing/ supplier | | | | | | 16 | 11 | | |
| Quality Management | 9 | | 14 | 10 | | 17 | 12 | 7 | |
| Resources Manag. | | 5 | | 9 | 13 | 15 | | | |
| Rework | | 17 | | | | | | | |
| Risk Management | | 4 | 15 | | 7 | 13 | 13 | | |
| Safety Management | 10 | | 16 | 7 | 4 | 20 | | | 7 |
| Value engineering | | | | | | | | | |

n = the number in the cell represents the ranking of each construction area within each ITC tool in ascending order

= the empty cell means there is no application using this ITC tool for this construction area




*(a) For each construction phase applying all ITC tools*




*(b) For each construction phase applying DM*

**Figure 6.5 : Percentage of the total number of published papers related to the construction phases during the period of the study (1992- 2001)**

**Table 6-4 : Percentage of published papers based on each ITC**

| ITC Tool | Construction Project Phases (%) | | | |
|---|---|---|---|---|
| | Pre-Design (%) | Design (%) | Construction (%) | Operation (%) |
| 3D | 5 | 29 | 57 | 9 |
| Sim | 5 | 7 | 78 | 10 |
| ES | 14 | 12 | 51 | 23 |
| KM | 10 | 3 | 62 | 25 |
| FS | 7 | 3 | 71 | 19 |
| DB | 11 | 25 | 41 | 22 |
| DM | 11 | 41 | 37 | 11 |
| GIS | 7 | 21 | 29 | 43 |
| VR | 0 | 58 | 30 | 12 |

**Criterion 5:** The percentage of papers published in scientific journals between 1992 and 2001 for each ITC tool, and for each construction area, which are generic and/or non-generic in their application. The term "generic" denotes an application that is not specified for a certain type of construction project, or not specified for a certain sub-area within each construction area. Figures (6.6) & (6.7) show the percentage of published papers that were generic within each tool and percentage of published papers that were generic within each construction area respectively. The study revealed also that the generic concept was applied more often using tools such as 3D, M, VR, and FS, while

other tools such as NN, GIS, Simulation, DB, and ES were used to apply the generic concept less often, especially in the case of the NN and GIS tools. The summary of results for the degree of generic applicability for each area is shown in Table (6.5).

**Criterion 6:** Integrated application or pairs of these tools during the period of the study between 1992 and 2001. It is categorized into four groups (not applicable, weak, moderate, or strong) based on the percentage of published papers in scientific journals making use of integration between pairs of ITC tools, over the total number of papers published during the period of the study. Figure (6.8) shows an example of the percentage of integration for GIS and ES compared to other tools. A summary of these results is shown in Table (6.6). The matrix shows the integrated pairs of the tools during the period of this study.

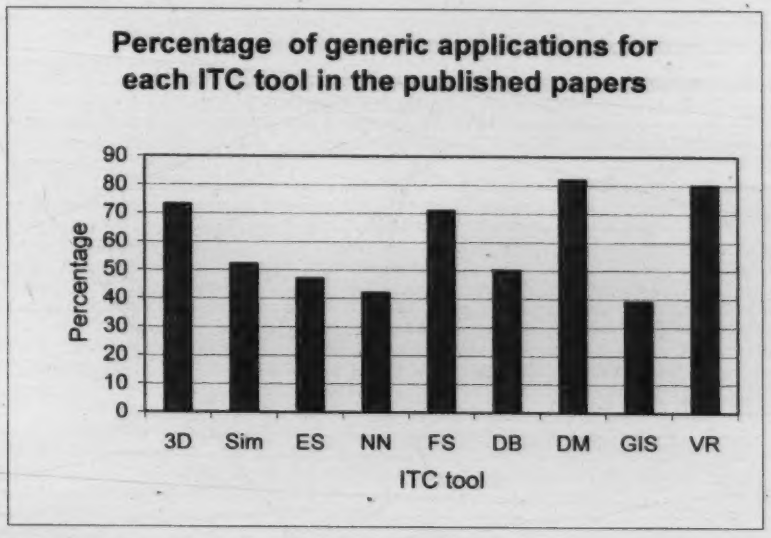



**Figure 6.6 : Percentage of generic applications for each ITC tool in the published papers**

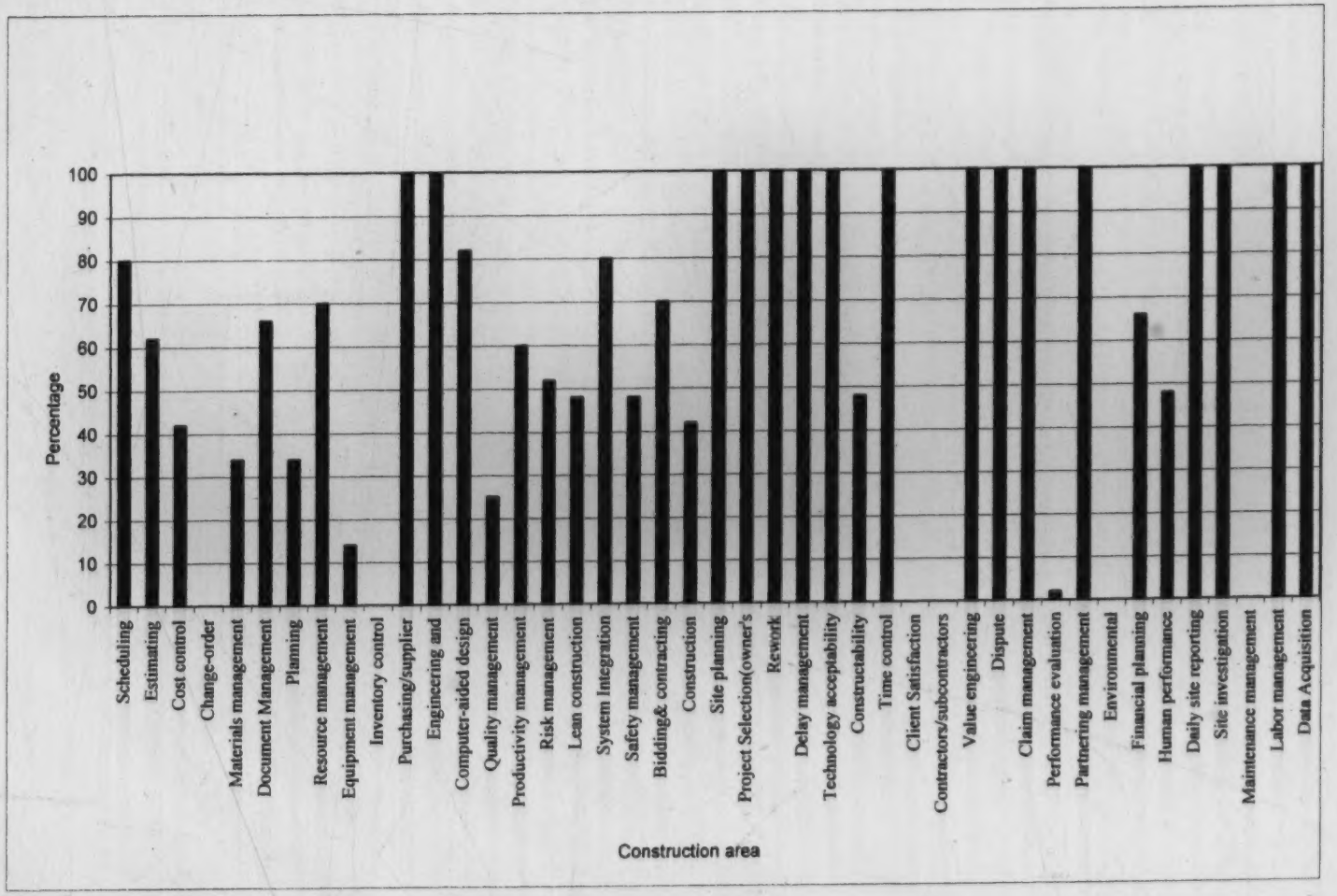
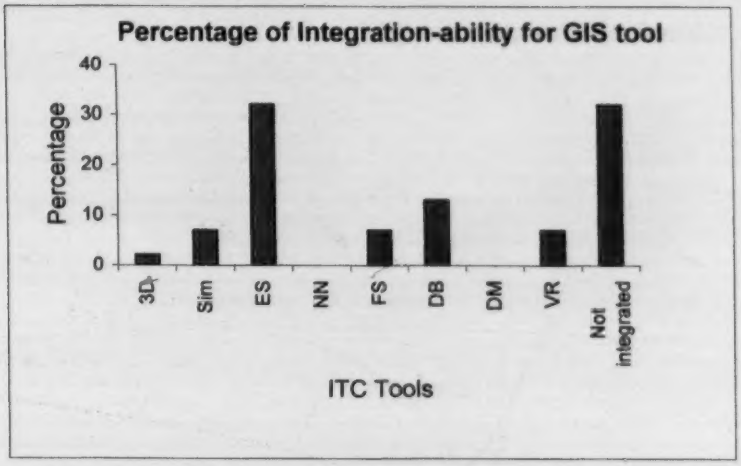



**Figure 6.7 : Percentage of generic applications of ITC tools in the published papers for each construction area**

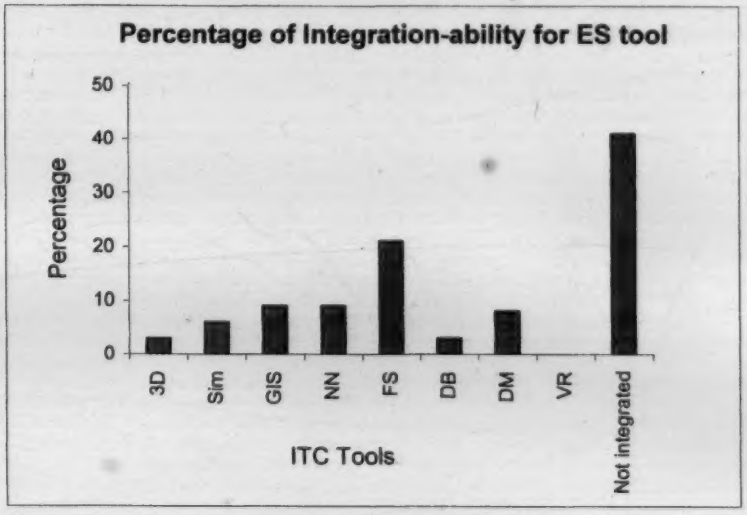
**Table 6-5 : Degree of generic-applicability for each construction area**

| | |
|---|---|
| Scheduling | M |
| Estimating | M |
| Cost Control | W |
| Change-order Management | $N_E$ |
| Materials Manag. | W |
| Document Manag. | M |
| Planning | W |
| Resources Manag. | M |
| Equipment Mang. | W |
| Inventory Control | $N_G$ |
| Purchasing/ supplier | H |
| Engineering and surveying | H |
| Computer-aided design and | M |
| Quality Management | W |
| Productivity Management | M |
| Risk Management | M |
| Lean Construction | M |
| Integration System | M |
| Safety Management | M |
| Bidding & Contracting | M |
| Construction Process/modeling | W |
| Site Planning | H |
| Project Selection (owner) | H |
| Rework | H |
| Delay Management | H |
| Technology Acceptability | H |
| Constructability | M |
| Time control | H |
| Client Satisfaction | $N_E$ |
| Contractors/Subcontractors | $N_E$ |
| Value engineering Application | H |
| Dispute Management | H |
| Claim Management | H |
| Performance Evaluation | M |
| Partnering Manag. | H |
| Environmental Manag. System | $N_E$ |
| Financial Planning | M |
| Human Performance | M |
| Daily Site Reporting | H |
| Site investigation | H |
| Maintenance Management | $N_G$ |
| Labor Management | H |
| Information Gathering | H |

H High
M Moderate
W Weak
$N_E$ Not exist
$N_G$ Not generic




(A): For GIS tool




(B): For ES tool

**Figure 6.8: Percentage of integration-ability**

**Table 6-6 : Matrix of integration-ability of each pair**

| | 3D | Simulation | ES | NN | FS | DB | DM | GIS | VR |
|---|---|---|---|---|---|---|---|---|---|
| 3D | | S | W | | | W | W | W | W |
| Simulation | S | | W | W | W | W | W | W | W |
| ES | W | W | | W | W | M | M | S | |
| NN | | W | W | | W | W | | | |
| FS | | W | W | W | | W | | W | |
| DB | W | W | M | W | W | | M | W | W |
| DM | W | W | M | | | M | | | S |
| GIS | W | W | S | | W | W | | | W |
| VR | W | W | | | | W | S | W | |

| S | Strong | W | Weak | M | Moderate | | N/A |
|---|---|---|---|---|---|---|---|

## 6.2.6. CONCLUSIONS

In this paper, the principal discussion has been around the utilization of nine ITC tools: Simulation, 3D, FS, ES, DB, M, GIS, NN, and VR within forty-three construction areas during the period of the study between 1992 and 2001. Six main analysis criteria were utilized to examine the application of the 9 ITC tools. The study used different techniques, graphics and tables in the six analysis criteria to highlight the facts. Emphasis was made on the value of integrations between different tools. The study showed several research areas that need more attention from researchers. This include application of IT tools to some construction management areas, and integration of some ITC tools. Also the needs to represent more generic ITC are illustrated. The results of the study are

limited to the period of the study and the number of scientific journals used. Future development of this research could focus on multiple-integration of these tools, examine other tools such as the genetic-algorithm, Taylor series, and analytical hierarchy approach; and extend the scope to conference proceedings publications.

## 6.2.7. REFERENCES


- Aouad, G., AlShawi, M., and Bee, S. (1996). "Priority Topics for Construction Information Technology." The International Journal of Construction Information Technology.
- Badger, A.A., Reinscmidt, K.A., and Grandt, A.R. (1987). "Project control system integration, project controls: needs and solutions." American Society for Civil Engineers, 88-100.
- Betts, M. (1992). "How strategic is our use of information technology in the construction sector." The International Journal of Construction Information Technology, 1(1), 79-97.
- Brandon, P.S. (1993). "Intelligence and Integration – Agenda for the Next Decade." Department of Surveying, University of Salford.
- CICA (1997). "Construction Industry Computing Association software directory."
- Cutting-Decelle, A.F., Dubois, A.M., and Fernandez, I. (1997). "Management and integration of production information in construction: reality and future

trend." The International Journal of Construction Information Technology, 5(2), 19-46.

- Fersko-Weiss, H. (1989). "One project, 3000 tasks: high-end project managers make the plans." PC Magazine, 8(9), 155-195.
- Fondahl, J.W., (1987). "The history of modern project management, precedence diagramming methods." origins and early development, Project Management Journal 18(2), 33-36.
- Froese, T.M. (1992). "Integrated computer-aided project management through standard object-oriented models." A dissertation submitted to the department of Civil Engineering of Stanford University for Ph.D. degree.
- Froese, T.M. (1999). "Interwoven threads: trends in the use of information technologies for the construction industry." A White Paper prepared for the Berkeley-Stanford CE&M Workshop.
- Ibbs, C.W., Ashley, D.B. Neil, J.M., and Feiler, F.W. (1987). "An Implementation Strategy for Improving Project Control Systems Project Controls: Needs and Solutions." New York: American Society for Civil Engineers, 101 – 112.
- KPMG (1993). "Building on IT – for quality." Construction Industry Computing Association and KPMG Peat Marwick Management Consultants, London, UK.
- Li, H., and Davies, H. (1998). "Construction information technology: where information is located." The International Journal of Construction Information Technology, 6(1), 63-71.

- Long, L., and Long, N. (1997). "Computers and information systems 5th Edition." London: Prentice Hall International.
- Miyatake, Y. and Kangari, R. (1993). "Experiencing Computer Integrated Construction." Journal of Construction engineering and Management, 119(2).
- Murtaza, M.b. and Fisher, D.J. (1993). "Neuromex-Neural Network System for Modular Construction Decision Making." Journal of Computing in Civil engineering, 8(2), 221 – 233.
- Nam, C.H. and Tatum, C.B. (1992). "Strategies for Technology Push: Lessons from Construction Innovations." Journal of Construction Engineering & Management, 118(3).
- O'Brien, M.J. (1991). "Strategic Implications of I.T. for the construction Industry, Internal report." Department of Computer Science, University of Nottingham.
- Oliver, S. (1994). "Identifying the future of Information Technologies within the changing Trends of the Architectural Profession, MSc dissertation." Department of Surveying, university of Salford.
- Paulson, B.C., Jr., 1972: Man-computer concepts for planning and scheduling, Journal of the Construction Division, 98(CO2), 275-286.
- Paulson, B.C. (1973). "Project planning and scheduling: unified approach." Journal of the Construction Division, 99(CO1), 45-58.
- Sun, M., and Aoud, G. (1999). "Control mechanism for information sharing in an integrated construction environment." Proceedings of 1st Conference for Concurrent Engineering in Construction.

- Tucker, R.L., O'Connor, J.T., Gatton, T.M., Gibson, ZG.E., Haas, C.T. and Hudson, D. N. (1994). "The Impact of Computer Technology on Construction's Future." Department of Civil Engineering, The University of Texas at Austin, Texas.

## 6.3. AUTOMATED DATA ACQUISITION SYSTEM

### 6.3.1. ABSTRACT

The data acquisition system plays an important role in the assessment of the project progress and productivity rates in the construction industry. It can be used to more effectively visualize, plan, and manage operations during their execution. It can also help to significantly improve the safety of equipment operation, and enhance a remote operator's spatial perception of the workspace, as well as increase the accuracy of the cashflow outlook table. Data acquisition is the process of obtaining data on a phenomenon of interest. In most cases, data acquisition involves the use of historical data from a similar completed previous project. However, the unique environment and variable conditions under which construction projects take place cause great difficulty in accurately calculating the factors, such as productivity, using the information from previous projects. The manual collection data methods used now in the construction field can become more reliable and more precise if the methods incorporate imaging processing technology. This technology has been implemented widely in many fields, except in work measurement data collection systems. This paper discusses the principles of methods of this technology, proposes a new methodology to collect data in the construction site using the webcam, analyses the collected digital 2D color images, and extracts the required data from them, as well as describing its limitations in the construction site. This paper summarizes the basis for method used and the barriers to their implementation in construction sites for data collection. An example case study obtained with this technology is provided. The developed algorithm was integrated into a

macro program so that the quantitative analysis could be performed automatically, saving time and limiting some operator bias.

### 6.3.2. INTRODUCTION

Recent advances in image processing, combined with the development of efficient numerical algorithms and an increased access to powerful computers, have made it practical to implement imaging processing technology in many fields. Imaging is routinely used in the biomedical, geophysical, and ocean graphical sciences, as well as in military applications, astronomy, oceanography, environmental assessment and many other fields (Pla-Rucki et al. 1995). The purpose of this paper is to discuss the opportunities and obstacles in improving data collection systems in construction sites by implementing image processing technology. The paper develops an algorithm for two modules using image processing technology to analyse the data collected using a fixed webcam in the site. This chapter presents innovative measures based on digital image processing to quantify the data required to measure and evaluate the time cycle for excavation equipment in the construction site during the construction process itself. For data acquisition in construction, especially the working measurement for equipment, the most widely used method to conduct surveys is based on human observation. This approach is extremely labor-intensive, prone to errors, and poses hazards. The present data acquisition systems used for work measurement in construction sites have many disadvantages and require new techniques that can eliminate them. The decrease of human involvement in these methods is one of the eight patterns described for the evolution of technological systems in the classical TRIZ theory, "The theory of Inventive

Problem Solving" (Savransky 2000). The inception of this theory occurred in the mid-1940s with the pioneering efforts of Genrich Altshuller in understanding how engineered systems have evolved since the dawn of humankind. This theory has eight patterns called the "Patterns of Evolution of Technological Systems". These patterns forecast the evolution of technological systems in engineering, which can be applied to the construction industry also. The eight pattern, called "Evolution Toward Decreased human Involvement", states that the line of decreasing human involvement on one level is changing from a system involving human action to substituting the human as an executing mechanism, then to substituting the human as an energy transformer, and finally to substituting the human as a source of energy. These steps of evolution are the same steps that the research intends to apply on the data acquisition system for work measurement in the construction site. The first step is similar to the use of on-site human observation for the data acquisition system. The second step is similar to applying video capturing and time-lapse film, and the third step is similar to the use sensors in the data acquisition system. The last step in the evolution is to apply image processing techniques within these systems.

There are a number of advantages to using automated data acquisition and visualization. The most obvious, perhaps, is that the decision support system can be run at anytime after the start of the project. As more data is collected from the project, the decision support system will become more accurate and precise in its predictions. Also, the actual working hours for each piece of equipment can be tracked. This is beneficial in tracking the productivity, and utilization of the equipment. Another advantage is that parallel activities can be tracked simultaneously. One example is tracking parallel excavation

activities in two sites at the same time instead of having manual-driven two separate systems to track them. This means that information stemming from parallel activities can be more accurately collected, taking into account the position of the activity in relation to other activities. More generally, a database system may be developed for some activities during the whole project's duration rather than simply collecting random data for some activities. This provides a much better picture of the project itself, and will result in more precise conclusions. The methodology developed in this research is based on retrieving digital images of a construction site using a webcam. The images used for this research are 2D color images with a size of 480 x 640 x 3, in which 3 expresses the three bands of colors (RGB). These images are analyzed using image processing techniques. Any captured image by a sensor is expressed as a continuous function, f(x,y), of two co-ordinates in the plane, and the sampling of this function into a matrix means image digitization. In the color images, each pixel will have with it a three-dimensional vector(r, g, and b) which provides the respective color intensities. So it is a type of 3D co-ordination of color space.

In the following sections, the paper will review the research developed in the construction area using image processing techniques, the main present methods used for work measurement in construction sites, as well as the main principles of image processing. The two developed methods will be discussed with their implementations in a case study. Their limitations and the recommendations for applying this approach will be discussed following that.

## 6.3.3. IMAGE PROCESSING APPLICATIONS

## BACKGROUND

### 6.3.3.1 IMAGE PROCESSING APPLICATIONS

Recently, Image processing has become one of the Information Technology tools in construction. Some major fields in construction use image processing as decision support tool. AbdelRazig (1999) used to assess constructed facilities surface quality. Wang (2000) presented a modified approach to collecting and processing pavement surface distress through the use of high-performance digital cameras for the acquisition of surface distress data. Rens et al. (2000) discussed the various applications of ACOUSTIC TOMOGRAPHIC IMAGING in Dams and structural engineering detection. Chen et al. (2002) have discussed the application of the multi-resolution pattern classification (MPC) method for steel bridge coating assessment. Kim et al. (2002) developed the "laser-based aggregate scanning system" (LASS) to rapidly and accurately characterize the three-dimensional shape properties of unbound stone aggregates. Chael et al. (2001) described, in his paper, the development of an automated data interpretation system for sanitary sewer pipelines using image processing and a neuro-fuzzy approach. Karimi et al. (2000) discussed the results of an evaluation of the accuracy of descriptive inventory data collected by three different Mobile Mapping Systems (MMSs). Another Important field of application for image processing in construction is the Data Acquisition System. Much research has been developed in this area such as: the Robotics Institute at Carnegie Mellon University developing the Autonomous Loading System (ALS), which uses a complex system of two scanning laser rangefinders to recognize and localize a dump

truck and measure the soil-surface contours by analysing the raw point clouds data (Stentz, 1998); Cho et al (2002) developed a new feasible framework for rapid local area workspace modeling by combining human perception, pre-stored CAD objects, and the use of simple sensors, such as single-axis laser rangefinders and remote video cameras. Stone et al. (1999) developed a virtual reality representation of the construction site, equipment, and the steel frame being built at a laboratory. The construction process was simulated in the augmented simulation world in real time. A video capture of the actual construction process was acquired and compared with the augmented simulation representation in real-time. The Laser Detection and Ranging (LADAR) and 3D laser scan systems have been used intensively as an imaging processing tool for construction site data acquisition system research. Beliveau (1996) used a laser scan system, called Odyssey, for the 3D position measurement of a construction site. Cheok et al. (2000) developed a system using high speed, precision laser radars (LADARs) to determine geometry changes in construction materials for assessment and documentation in terms of 3D as-built models of the construction process. Shih used a 3D laser scan system to retrieve the information on site occurrences, in order to describe the building construction process based on what really occurs at a site through the measurement of geometric changes. Although LADARs or the 3D laser scan systems had many applications in data acquisition systems for construction site, especially to measure its metrology and to be used as a 3D spatial measurement tool, its application as data acquisition tool is still limited due to the following reasons mentioned by Stone et al. (2002): the slow speed of operation, its bulkiness, the high cost, widely varying accuracy that presently lacks standardized calibration metrics, and the methods used for processing the data as and

offline methods. Abeid et al. (2002) developed an algorithm to detect a structural component in a photograph of a construction site based on RGB ranges for different types of construction materials that have been saved in a library. The system is based mainly on an edge detection approach.

Although all of the aforementioned image processing systems have had significant influence in developing data acquisition systems for construction sites, none of these systems tried to track the timecycle of equipment or measure the work productivity. They tried mainly to detect geometric changes in the site. Also, all of these systems are unsuitable for construction sites due to their high cost, low speed, and complicated processes.

### 6.3.3.2 WORK MEASUREMENT TECHNIQUES

One main purpose of measuring productivity is to increase it and to be able to measure the effects of using new techniques to improve it. Dozzi et al. (2003) reported some usual techniques for measuring productivity in construction sites. Some of these techniques are as follows: field rating, work sampling, five minute rating, crew-balance charts, and the method productivity delay model. All of these methods depend on the data collection sampling because the time spent collecting data has to be limited. The present methods used for data collection systems range from on-site monitoring using a stopwatch, the use of video tapes, time-lapse film analysis, or to attaching sensors to the required equipment to be observed. Some of the main disadvantages of applying these methods using the usual sampling data collection are:

1) data are not guaranteed, which can be used as input data for any decision support system during the construction process. The collection and analysis of this data is usually taking by time to been developed, which affects the reliability of the decision support system results.
2) They can not track many parallel activities or cycles (for example excavation and concrete curing).
3) They are highly labour dependant, which raises the cost for collecting these data.
4) In the case of using sensors, it is highly costly.
5) They are not able to track the specified instance of any resource. For example, they cannot track each excavation truck alone, as well as tracking other trucks.
6) High accuracy is not achievable by using these methods. They depend only on some random observations during the project period to be used as a reference for the data analysis.

### 6.3.3.3 DIGITAL IMAGE PROCESSING

In this section, a review of the basic concepts and steps towards image processing will be done. Digital image processing consists of the conversion of video or webcam pictures into digital form and applying various mathematical procedures to extract significant information from the picture (Masad et al. 1998). It is fast becoming a versatile tool in the construction field to characterize the internal structure of materials. Although digital image processing has increasingly been used in characterizing a number of construction materials, its use in data collection has not been fully utilized, especially in the area of 2D images. The image consists of sampling points that are ordered in the plane, and their

geometric relation is called the grid. The grid can be square or hexagonal, and the one used in this research is the square representation (Sonka et al. 1999). Each sampling point in the grid corresponds to one picture element (pixel), which is not further divisible from the image analysis point of view. A digital image consists of picture elements with a finite size of pixels that carry information about the brightness or color intensity of a particular location in the image. Another important concept in digital images and used here in this research is adjacency. Any two pixels are called 4-neighbors if they have distance D4 = 1 from each other. Analogously, 8-neighbors are two pixels with D8 = 1 as illustrated in Figure 6.9 (Sonka et al. 1999).

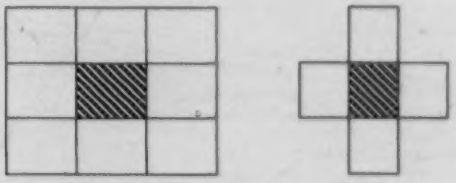


**Figure 6.9** : Pixel neighborhoods (Sonka et al. 1999)

Another important concept of the digital image is the region. The region is a set of pixels where each pair of pixels in the set is contiguous. Contiguous means that there is a path between the two pixels in the image, where the path is a sequence of points or pixels from one pixel to another one. Another two important concepts are the border and noise. The border is the set of pixels within a region, R, that have one or more neighbors outside of R.

Real images are often degraded by some random errors, and this degradation is usually called noise. It can occur during image capture, transmission, or processing, and may be

dependent on, or independent of, the image content. Some famous types of noises are Gaussien noise, additive noise, multiplicative noise, quantization noise, and impulsive noise. There are four levels of image data representation: iconic images, segmented images, geometric images, geometric representations, and relational models. Also, there are four different types of traditional image data structures: matrices, chains, topological data structures, and relational structures. This research focuses on applying image processing to the matrices structure for the iconic image. For more details on other types, please refer to Sonka et al. (1999). The iconic image is the lowest representation level of the image. It consists of images containing original data; integer matrices with data about pixel brightness. On the other hand, the matrix is the most common data structure for the low-level representation of an image. Elements of the matrix are integer numbers corresponding to brightness, color intensity, or to another property of the corresponding pixel of the sampling grid.

In this section, we will review some of the basics steps towards image processing. Image segmentation is one of the most important steps leading to this. Its main goal is to divide an image into parts that correlate with objects in the real world, as taken by the image. There are two types of segmentation; the first one is the complete segmentation, which results in a set of disjoint regions corresponding uniquely with objects in the input image. The other type is partial segmentation, in which regions do not correspond directly with the image objects. Our research uses the first type of segmentation, which is complete segmentation. The complete segmentation of an image R is a finite set of regions R1,……., Rs,

$R = U^{s}_{i=1} Ri \qquad Ri \cap Rj = 0 \quad i \neq j$.....(3.1) (Sonka et al. 1999).

The simplest way of going about this segmentation process is called thresholding. It depends on the character of each object or image region, that each one has a constant reflectivity or light absorption of their surfaces. For that, the object and its background can be segmented according to its brightness constant or threshold. The threshold is the transformation of an input image, f, to an output (segmented) binary image, g, as follows:

$g(i, j) = 1$ for $f(i, j) \geq T$

$= 0$ for $f(i, j) < T$ ..... (3.2) (Sonka et al. 1999)

Where T is the threshold, $g(i, j) = 1$ for image elements of objects, and $g(i, j) = 0$ for image elements of the background (or vice versa).

Another type of thresholding is called semi-thresholding, in which the gray or color level information of specified objects are left in the images as follows:

$g(i, j) = f(i, j)$ for $f(i, j) \geq T$

$= 0$ for $f(i, j) < T$ ..... (3.3) (Sonka et al. 1999)

The algorithm used for semi-thresholding is as follows:

Search all the pixels $f(i, j)$ of the image f. An image element $g(i, j)$ of the segmented image is an object pixel if $f(i, j) \geq T$, and is otherwise a background pixel.

**Red/Green/Blue (RGB) Images**

An RGB image is a color image. Colors are described in three basic color components red, green, and blue; hence, the name RGB. RGB images are also represented in the matrix

form. For an RGB image, three layers of matrices are required. Thus, each pixel has three values of red, green, and blue. When an image has a 24-bit color depth, each color

component has an eight-bit level. Many different colors can be represented through a combination of the three layers of the eight-bit level. Figure 6.10 shows an RGB image that is represented in the form of a three-layer matrix.

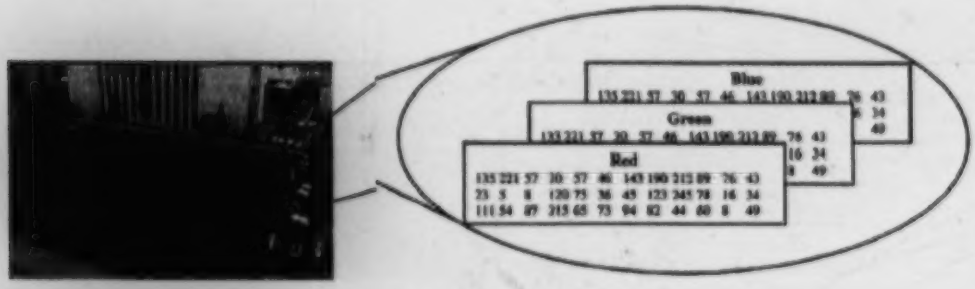



**Figure 6.10 :RGB Image**

The color-intensity histogram gives the intensity of a color image without the location information. For an image f (x, y) with a discrete color-intensity range {0, 1, 2, . . . , 255}, the color-intensity histogram H(z) is the discrete graph plotted with the number of pixels at color-intensity z versus H(z) = [ f (x, y) = z] dx dy for each band of the color (RGB) image. Figure 6.11 shows a histogram of one of the bands for a color image. The horizontal axis presents the color-intensity (z) of the color (RGB) image, and the vertical axis represents the frequency [H(z)]. Also, the mesh diagram of any color image can be good guide for image processing techniques. It shows the 3D plot of color intensity for the three bands among the image boundary as shown in Figure 6.11.

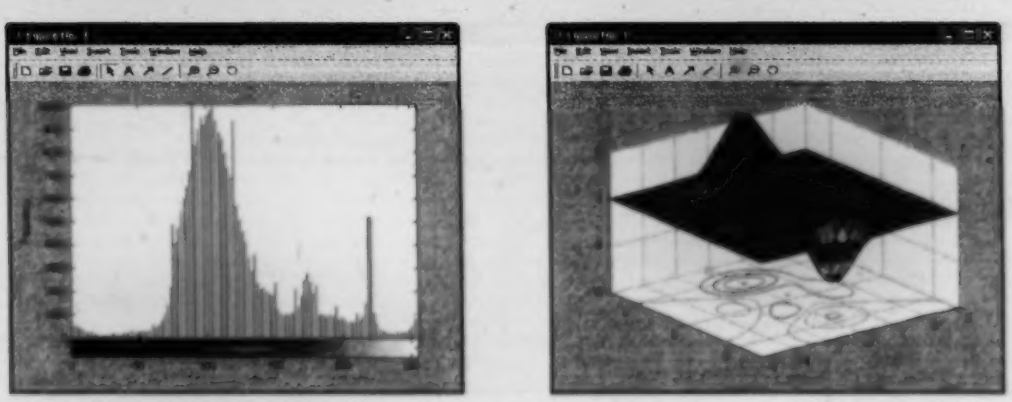


**Figure 6.11 : Histogram of One band and Mesh diagram for Color-Intensity Image**

Another important concept of image processing is block processing operations. Certain image processing operations involve processing an image in sections called blocks, rather than processing the entire image at once. The block processing function does the work of breaking the input image into blocks, calling the specified function for each block, and reassembling the results into an output image. One of the main algorithms used in image processing is subtracting images. Subtraction is primarily a way to discover the differences between images. The parts of the picture that are essentially unchanged in the two images cancel out and appear as a uniform background, except for minor variations due to the precision of digitations, changes in illumination, etc. Subtracting one image from another effectively removes, from the difference image, all the features that do not change, while high-lighting those that do. If the lighting and geometry of the view is consistent, the only differences in pixel values where no changes occur are statistical variations in the brightness, due to the camera or electronic noise. Subtraction can be used to track object motion, if the features are large enough and the sequential images are acquired fast enough that they overlap in successive frames. In this case, the subtraction

shows a bright area of mismatch that can be measured. The direction, location, and velocity of an object can be easily determined using this technique. Another important concept in image processing is sliding neighborhoods. For a sliding neighborhood operation, a temporary matrix is created, which has a separate column for each pixel in the original image. The column corresponding to a given pixel contains the values of that pixel's neighborhood from the original image. Figure 6.12 illustrates this process. In this Figure, a 6-by-5 image matrix is processed in 2-by-3 neighborhoods. The process creates one column for each pixel in the image, so there are a total of 30 columns in the temporary matrix. Each pixel's column contains the value of the pixels in its neighborhood, so there are six rows. The process zero pads the input image as necessary. For example, the neighborhood of the upper left pixel in the Figure has two zero-valued neighbors, due to zero padding. The resulting values are then assigned to the appropriate pixels in the output image.

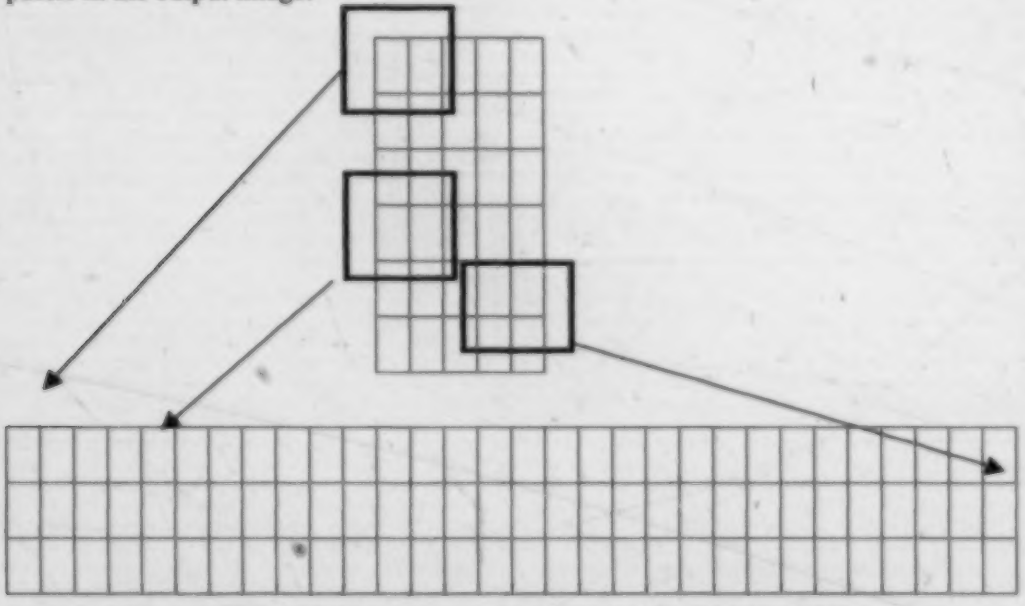


**Figure 6.12 : Creating a Temporary Matrix for Sliding Neighborhood**

### 6.3.4. FRAMEWORK

The equipment used for the proposed image analysis methodology consisted of the following devices and software.

1) Image processing and analysis program. Image Analysis Toolbox of MATLAB release 13.0, which were developed by Mathworks, have been used for that purpose.
2) Visual Communication Suite that consists of a digital network Webcam AXIS 2100. It contains a high performance web server, which gives the ability to connect it directly to the internet. The resolution of the captured image is 640 X 480 and they are 2D color images. The number of pixels is 640 in the x-axis direction, and 480 in the y-axis direction as shown in Figure 6.13. The size of the image is roughly 56.0 KB, and its graphic file type is a JPG (Joint Photographic Experts Group) file. The webcam is connected directly to the backbone of the LAN of the University of Alberta through a router. The images are captured on a server using File Transfer Protocol "FTP". The server sends a copy of these images, which have the time and date of capturing on the name of each image, to another web-server. This server can publish these images on the website as shown in Figure 6.14. At the same time, copies of all these images are saved in a directory on another machine to burn CDs, to be used in the image processing process.
3) A Windows XP based computer system with 128-MB RAM, and Pentium® 4 CPU 2.40GHz processor.

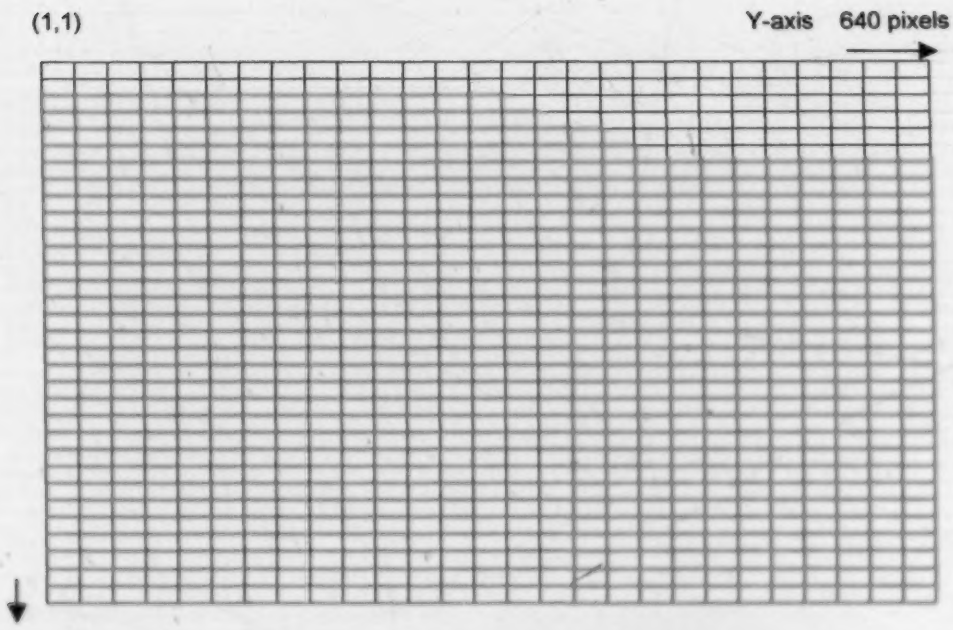



**Figure 6.13 : Image size and coordinates**

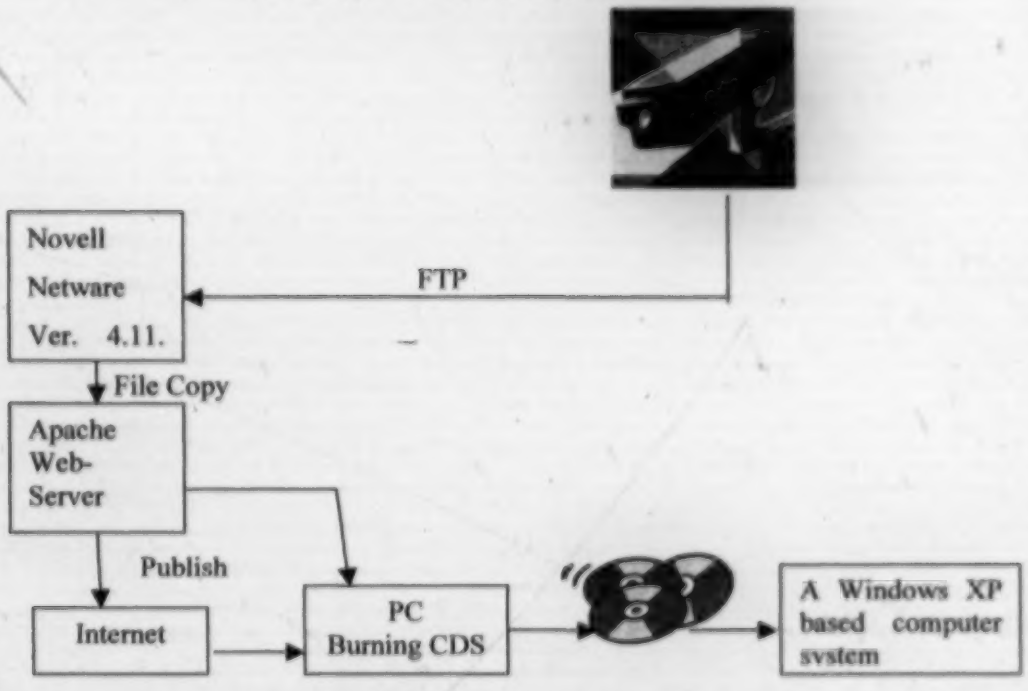



**Figure 6.14 : Image Capturing System**

**Case Study: NREF** - Visualization and Automated Production Cycle Analysis

The study that occurred during the construction of the Natural Resources Engineering Facility (NREF) building at the University of Alberta was concerned in part with developing a process for monitoring and analyzing a project's progress in real-time. Such a process would benefit both the monitored project itself as well as subsequent projects. Prior to this development, a project could only draw upon historical data in order to model its construction process. The uniqueness of each project, however, both in terms of environment and purpose, make the accurate calculation of factors, such as productivity, extremely difficult when based on previous project data alone. With the development of automated data acquisition, the data used in any decision support modeling can be acquired from earlier within that same project rather than from a previous similar project. Data can then be used to adjust any decision support system's factors. The decision support system could be run at any given point in the project. This means a much more accurate and up-to-date prediction of the project's progress. The automated data acquisition system uses image processing in this project to measure the excavation truck's cycle times, its unloading and loading time, in addition to its location in the image (X,Y coordinates), which can be used for other decision support system such as 3D simulation tool. The site contains 12 excavation trucks. The aim of this methodology was to track one of these trucks (as shown in Figure 6.15) by using the recorded images of the webcam and techniques of image processing. The same methodology can be applied for the other 11 trucks later, with some limitations due to the similarity in their main color. The images were recorded using a webcam, which took an

image of the worksite from a fixed position every ten seconds for some periods and every 30 seconds for other periods, to compare the results of both imaging intervals. These pictures were used to determine productivity improvement and to measure work. A computer then processed the images, collecting data directly by measuring the time of loading and unloading for these trucks.

**Figure 6.15 :** Images of recognized truck

The calculation depends on saving the time of truck entering the site and its time of existence on the site, depending on the manual interface with the user to define the start image, the trucks to be tracked, and the location of entrance and existence on the site. After that, the validation of collected data using this system will be evaluated against data collected from the same images using human observation. The comparison will highlight the percentage of precision for this new method.

### 6.3.5. MODELS DEVELOPED

**Developed image processing algorithm**

The first step regarding the design of this approach was applying some main algorithms and approaches of image processing like subtraction, thresholding, block processing operations, and sliding neighbourhood techniques. This approach faced many limitations and disadvantages after its application in the case study as follows:

1) The shadow of the truck affects the inverse subtraction of two images. Because it may appear as the truck was still in the same position, when it had actually moved to another place.
2) The long processing time due to the complicated mathematical processes.
3) The existence of other equipment objects in an image after subtraction, such as an excavator, due to its movement from one image to a subsequent one.
4) The images were highly affected by environmental changes (rain, sunlight, clouds,…etc.)
5) Its accuracy doesn't exceed 60 % due to previous causes.

Another new proposed methodology consisting of two main modules has been designed, as shown in its general description flowchart in Figure 6.16. The first module is responsible for the manual recognition of specified objects required to be tracked in the construction site (for example excavation trucks), and then to save the specified values to be used in the second module. The user is responsible at this stage to define the required objects to be recognized. The second module is responsible for the automated recognition of this object in the images and defines its time, date, and location (X and Y coordinates) when it appears. The results will be sent to a database using Excel sheet, which has a

macro capable of recognizing the time of entrance and the existence of the object on the construction site, and is able to calculate the duration of loading time and unloading time for each truck. The loading time here includes waiting time. As well the unloading time includes traveling times. Recognizing these times at a more detailed level is out of the scope of this research.

One of the main problems facing this approach is the effect of many outside factors on the apparent color of an object, such as: the different times of the day, different weather conditions, and at various positions and orientations of the object and camera. A wide range of proposals have been reviewed as discussed in detail in the work of Batlle et al. (2000). Most of these proposals are based on RGB components of color images, which can provide valuable information. One of these approaches proposed a set of color features $I_1$ =(R+G+B)/3, $I_2$ = (R-B) and $I_3$= (2G-R-B)/2 by Ohta et al. (1980). The developed approach here used $I_1$ as one of its feature for recognition of required objects as shown in the following sections.

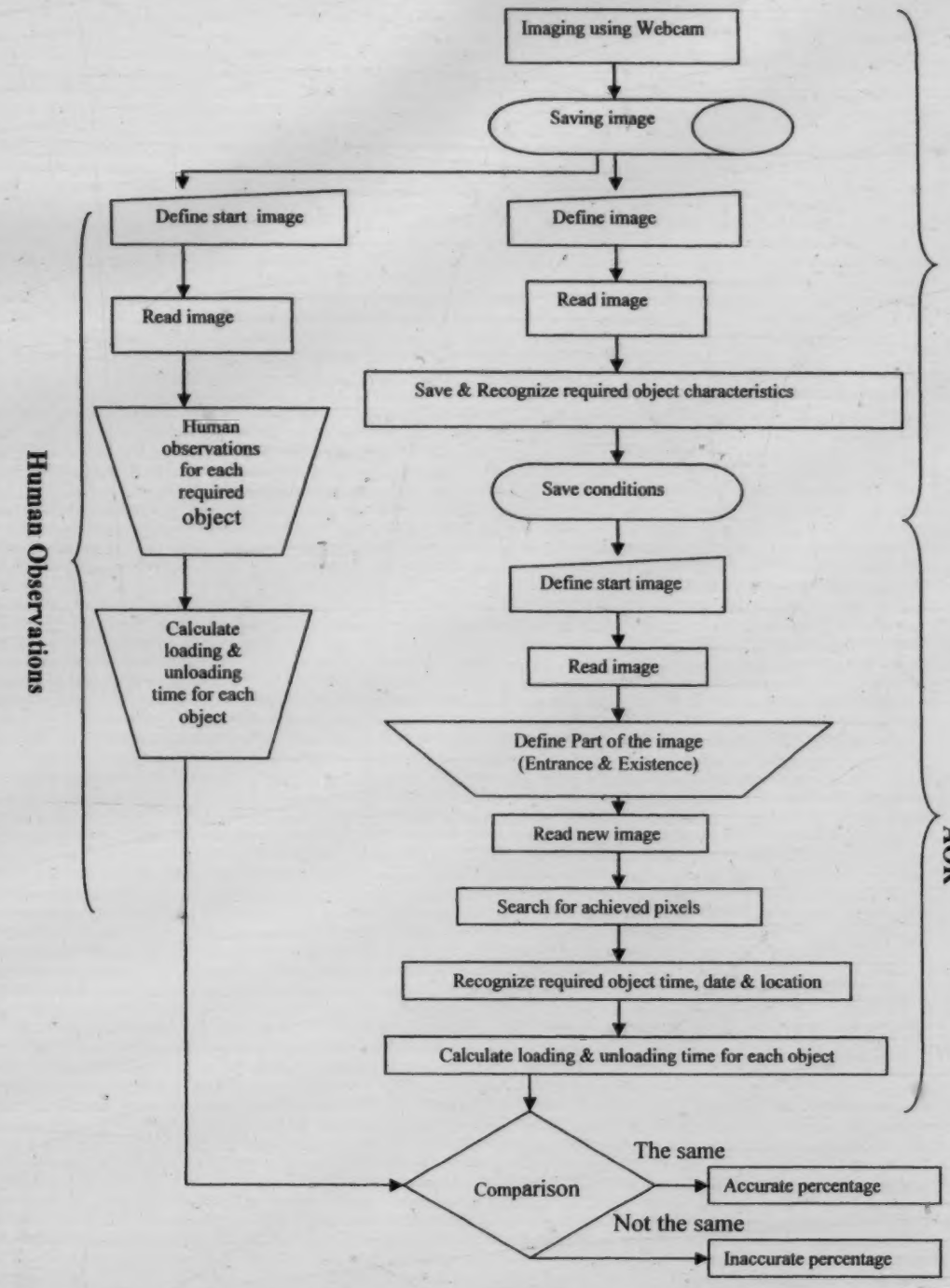



**Figure 6.16 : General description of proposed method**

The algorithm for each module as following:

**Algorithm of first module (Manual Object Recognition (MOR) Module):**

1) Clear all work space elements.
2) Define the path and name of the image that has the required object.
3) Read the image
4) Select manually the part of the object that can recognize it in terms of its RGB color bands relations as shown in Figures 6.17 and 6.18.

**Figure 6.17 : Manual selection of required object**

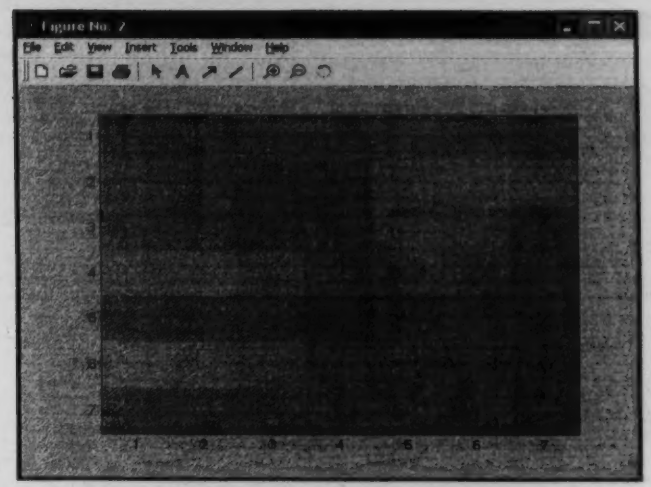



**Figure 6.18 : Selected part of required object**

5) Recognize only an object of 7x7 pixels size, which is suitable for webcam resolution (Figure 6.18).

6) Save the matrix that has values of each RGB color band for the selected object in the database, to be used in the future for values comparison.

7) Calculate the average of the three main RGB colors for the selected object (K $(i_j)$).

8) Calculate the median of median for K $(i_j)$ ( Q= median(median(K$(i_j)$)). This is to ensure the calculation of the median for columns of the matrix and then for the rows of the matrix.

9) Calculate the relations between each component of RGB color of the selected object as follows:

H1=R/G

H2=G/B

H3=R/B

Figure 6.19 shows a sample of color intensity curve for the three main bands of selected pixel in the selected part of the object.

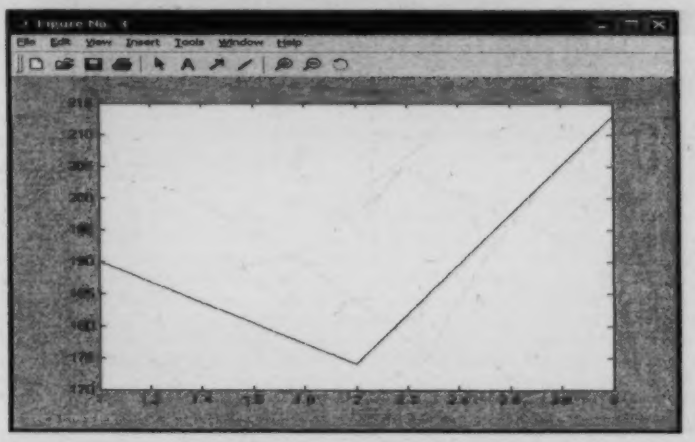



**Figure 6.19 : A sample of color intensity for the three main bands of selected pixel within a selected object.**

10) Calculate the mean for each value as following:

Cmean1=mean (mean (H1))

Cmean2=mean (mean (H2))

Cmean3=mean (mean (H3))

11) Save the calculated values of steps 8 and 10 for future comparison.

12) Repeat the steps 2 through 11 for each required object (excavation truck in this case) to be recognized.

**Algorithm of second module (Automated Object Recognition (AOR) Module):**

1) Define the path and name of the first image that has been taken by the webcam in the morning.

2) Recognize the date and time of the image and save that in variables.

3) Read the image.

4) Manually select the rectangular part of the first image that has the entrance and existence of the construction site as shown in Figure 6.20.

**Figure 6.20 : Original first image in the working day**

5) Define the minimum length of the moving block, which will be recognized (length = 7).

6) Define the minimum value for color intensity in order to neglect the noises in some images using the threshold method (the selected value is 50).

7) Read the new selected part of the image as the new image, as shown in Figure 6.21.

**Figure 6.21 : Selected part of the image as a new image**

8) Change the type of data of the new image to be double to ensure correct calculations.

9) Add a value of 5 to the color intensity of the new image to ensure that the results of division will not be infinity in the case that some pixels have values of zero.

10) Calculate the following for each pixel in the selected new image:

    a. Calculate the average of the three main RGB colors for the selected object (K (i,j)).

    b. Calculate the median of the median for K (i,j) ( Q= median(median(K(i,j)). This is to ensure calculation of the median for columns of the matrix and then for the rows of the matrix.

    c. Calculate the relations between each component of RGB color of the selected object as follows:

H1=R/G

H2=G/B

H3=R/B

d. Calculate the mean for each value as following:

Cmean1=mean (mean (H1))

Cmean2=mean (mean (H2))

Cmean3=mean (mean (H3))

11) Define the range value, which can be used for the comparison between the calculated mean value and the relative one in the first module. The suggested range value with the calculated relations between values of RGB color intensity for each pixel will be able to solve the problem of sun light, change of environment conditions, and to recognize each object alone.

12) Compare the calculated values of each pixel with the relative stored values from first module.

13) Define the X and Y coordinates of each pixel in the achieved comparison conditions, and store them using the following algorithm (Figure 6.22):

a. Collect the local x, y coordinates of the truck in the new image.

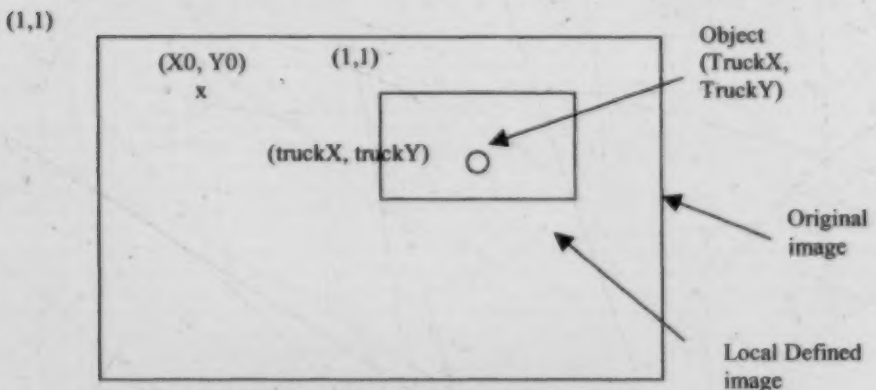
b. Calculate its global coordinates in the original image using following the equations:

TruckX = truckX + X0 – 1

TruckY = truckY + Y0 – 1

14) Calculate the median of all recognized global coordinates, which will be the location of the required object to be recognized. The aim of the median is to

ensure the correct location of the object and to delete noise, because some selected pixels which achieve comparison conditions will be outside recognized object. But, the main concentration of the pixels will be within the object boundaries. Using the median value is more precise than using the mean value, because, for example, if we have the required object and two other away points achieving all conditions as shown in Figure 6.23, then the median will give us the point in the object, because it has many similar points inside it. But, the mean will give us the average value for the coordinates, which can be in the middle distance of the required object and these points (outside the object boundary).




truckX = Local X coordinate in the local defined image
truckY= Local Y coordinate in the local defined image
X0 = Global X coordinate of upper left point for the image
Y0 =Global Y coordinate of upper left point for the image
TruckX = global X coordinate for the selected object.
TruckY = globalY coordinate for the selected object.

**Figure 6.22 : Algorithm of X, Y coordinates**

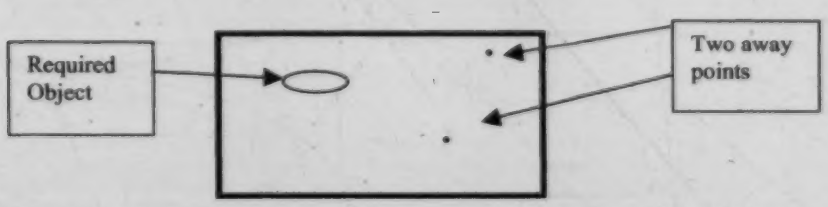


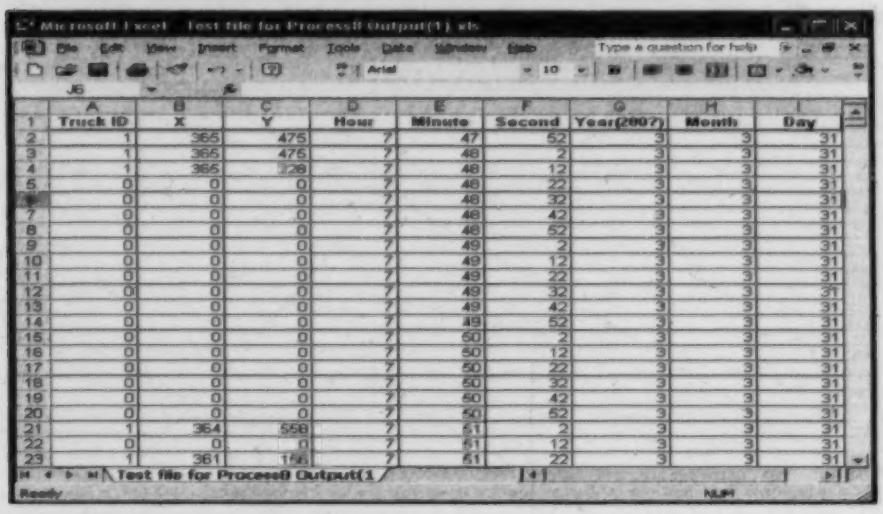

**Figure 6.23 : Median method to define accurate coordinates of objects**

15) Save the time and date of the image for the recognized position with an ID number for each object in the database Excel sheet as shown in Figure 6.24.

16) Repeat automatically steps 2 through 15 for each image until the end of the working day.

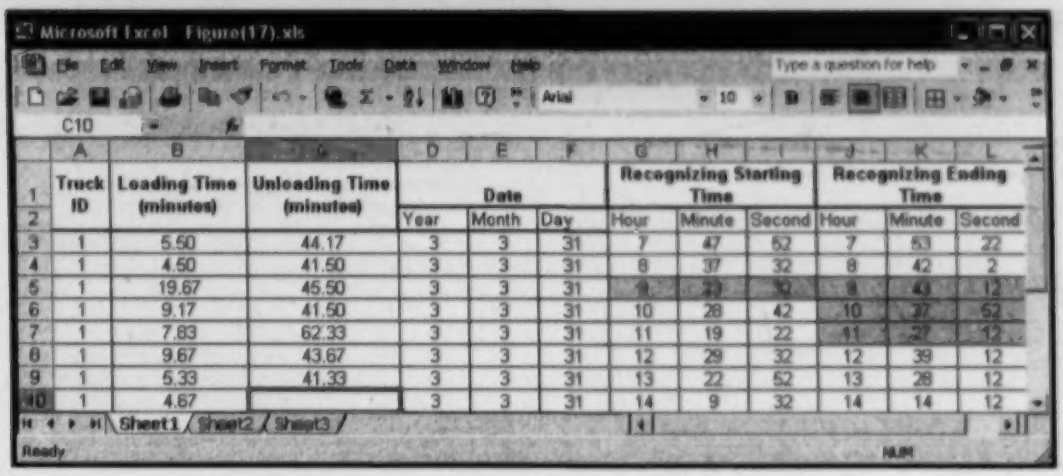
17) Calculate the duration of the loading and unloading time for each object using the developed macro in Excel sheet as shown in Figure 6.25.

18) Repeat steps 1 through 17 for each working day.



| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Truck ID | X | Y | Hour | Minute | Second | Year(2007) | Month | Day |
| 2 | 1 | 365 | 475 | 7 | 47 | 52 | 3 | 3 | 31 |
| 3 | 1 | 365 | 476 | 7 | 48 | 2 | 3 | 3 | 31 |
| 4 | 1 | 365 | 228 | 7 | 48 | 12 | 3 | 3 | 31 |
| 5 | 0 | 0 | 0 | 7 | 48 | 22 | 3 | 3 | 31 |
| 6 | 0 | 0 | 0 | 7 | 48 | 32 | 3 | 3 | 31 |
| 7 | 0 | 0 | 0 | 7 | 48 | 42 | 3 | 3 | 31 |
| 8 | 0 | 0 | 0 | 7 | 48 | 52 | 3 | 3 | 31 |
| 9 | 0 | 0 | 0 | 7 | 49 | 2 | 3 | 3 | 31 |
| 10 | 0 | 0 | 0 | 7 | 49 | 12 | 3 | 3 | 31 |
| 11 | 0 | 0 | 0 | 7 | 49 | 22 | 3 | 3 | 31 |
| 12 | 0 | 0 | 0 | 7 | 49 | 32 | 3 | 3 | 31 |
| 13 | 0 | 0 | 0 | 7 | 49 | 42 | 3 | 3 | 31 |
| 14 | 0 | 0 | 0 | 7 | 49 | 52 | 3 | 3 | 31 |
| 15 | 0 | 0 | 0 | 7 | 50 | 2 | 3 | 3 | 31 |
| 16 | 0 | 0 | 0 | 7 | 50 | 12 | 3 | 3 | 31 |
| 17 | 0 | 0 | 0 | 7 | 50 | 22 | 3 | 3 | 31 |
| 18 | 0 | 0 | 0 | 7 | 50 | 32 | 3 | 3 | 31 |
| 19 | 0 | 0 | 0 | 7 | 50 | 42 | 3 | 3 | 31 |
| 20 | 0 | 0 | 0 | 7 | 50 | 52 | 3 | 3 | 31 |
| 21 | 1 | 364 | 558 | 7 | 51 | 2 | 3 | 3 | 31 |
| 22 | 0 | 0 | 0 | 7 | 51 | 12 | 3 | 3 | 31 |
| 23 | 1 | 361 | 154 | 7 | 51 | 22 | 3 | 3 | 31 |

**Figure 6.24 : Initial data collected using image processing system**



Microsoft Excel - Figure(17).xls

| | Truck ID | Loading Time (minutes) | Unloading Time (minutes) | Date | | | Recognizing Starting Time | | | Recognizing Ending Time | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year | Month | Day | Hour | Minute | Second | Hour | Minute | Second |
| 3 | 1 | 5.50 | 44.17 | 3 | 3 | 31 | 7 | 47 | 52 | 7 | 53 | 22 |
| 4 | 1 | 4.50 | 41.50 | 3 | 3 | 31 | 8 | 37 | 32 | 8 | 42 | 2 |
| 5 | 1 | 19.67 | 45.50 | 3 | 3 | 31 | 9 | 23 | 32 | 9 | 49 | 12 |
| 6 | 1 | 9.17 | 41.50 | 3 | 3 | 31 | 10 | 28 | 42 | 10 | 37 | 52 |
| 7 | 1 | 7.83 | 62.33 | 3 | 3 | 31 | 11 | 19 | 22 | 11 | 27 | 12 |
| 8 | 1 | 9.67 | 43.67 | 3 | 3 | 31 | 12 | 29 | 32 | 12 | 39 | 12 |
| 9 | 1 | 5.33 | 41.33 | 3 | 3 | 31 | 13 | 22 | 52 | 13 | 28 | 12 |
| 10 | 1 | 4.67 | | 3 | 3 | 31 | 14 | 9 | 32 | 14 | 14 | 12 |

Sheet1 / Sheet2 / Sheet3

Ready

**Figure 6.25 : Calculated times using developed macro**

## 6.3.6. VALIDATION

The developed system has been applied in the case study of the NREF. The system applied around 3500 images. The results of the collected loading and unloading time for the required truck using 10 second imaging intervals are shown in table 6.7. Also, the results of the human observation using the same images are shown in the same table. In the case of using 10 second imaging intervals for the first developed approach, the time needed for processing was roughly 40 minutes per 1500 images. And the time needed for processing the images of 10 second imaging intervals, also, but for the final proposed approach, was roughly 6 minutes per 1500 images. And, in the case of human observations for the same Figure of images, it was around 480 minutes (8 hours) per 1500 images. The results showed that the accuracy of this approach is 88% for the 10 seconds imaging interval, and 30% for the 30 second imaging intervals. This can be defined due to the non-appearance of recognized truck in semi-interval images between its entrance

and its existence from the site in the case of the 30 second interval imaging. This percentage is calculated according to the percentage of correct collected data for both trucks (in terms of time and duration) compared with the total collected data using this system.

**Table 6-7 : Comparison of collected data using new system and human observations**

| 10 Seconds Imaging | | | | | | |
|---|---|---|---|---|---|---|
| | | New Approach | | Human Observations | | Correct/InCorrect Observations |
| Date | Observation Number | Loading Time | Unloading Time | Loading Time | Unloading Time | |
| 31.03.2003 | 1 | 5.50 | 44.17 | 5.50 | 44.17 | C |
| 31.03.2003 | 2 | 4.50 | 41.50 | 4.50 | 41.50 | C |
| 31.03.2003 | 3 | 0.00 | 0.00 | 19.67 | 45.50 | IC |
| 31.03.2003 | 4 | 9.17 | 41.50 | 9.17 | 41.50 | C |
| 31.03.2003 | 5 | 7.83 | 62.33 | 7.83 | 62.33 | C |
| 31.03.2003 | 6 | 9.67 | 43.67 | 9.67 | 43.67 | C |
| 31.03.2003 | 7 | 5.33 | 41.33 | 5.33 | 41.33 | C |
| 31.03.2003 | 8 | 4.67 | N/A | 4.67 | N/A | C |
| | | Percentage of Correct observations | | | | [redacted] |

**Advantages of using this system**

After applying these modules to the specified case study, and comparing their results with actual results in the collected images, the following advantages over other present data acquisition systems and over the first developed algorithm have been found:

1) Collecting data at the lowest abstract level of construction process. This increases the reliability and accuracy of the developed decision support model based on these data as input data.

2) The ability to develop a decision-support system based on actual data instead of using historical data.

3) Its practicality and reliability, which means that this system has been developed under a real and actual environment of a construction site, and not under a laboratory environment. This gives the system more reliability.

4) The ability to track many parallel activities and cycles at the same time.

5) Inexpensive compared to using sensor system or using human observation, either on-site or from recorded time-lapse film or video tapes.

6) The ability to manage equipments and resources individually (e.g. manage each truck productivity instead of tracking all of them together for an excavation process).

7) It can be used for site layout management.

8) Developing a database system for each activity duration during the whole project duration instead of collecting some random observations for some activities, which is less precise.

9) It can be used as geometric reference for any developed virtual-reality or 3D simulation model.

10) The ability to run the decision support system at anytime after start of the project.

11) The high accuracy results, which are more than 90%, in a comparison to actual data in the collected images.

### 6.3.7. RECOMMENDATIONS

Also some recommendations have been made following the application of this methodology in the mentioned case study. They are as follows:

1) The image resolution should have higher values. It is recommended to have at least 1024 X 768, which can give more control over the recognition of many objects in the construction site.
2) The entrance and existence of the project should preferably be unique and fixed.
3) After comparing the results of both the 10 second and 30 second intervals, it is recommended to decrease the time interval of imaging using the webcam to a time less than 10 seconds. This will help to check easily if the truck has existed in the site at more than one position for the same time. The recommended time interval is between 1 and 3 seconds, which will solve the conflict raised by the similar color for various trucks, or various equipment in the site. Because according to the maximum speed of the specified equipment in the construction site, the travel distance of this equipment in the image can be easily identified and used as a condition to recognize each place of equipment alone, even if there is more than one that has the same color.
4) In the case that the last recommended point can not be achieved due to a shortage in hardware, an obviously colored object can be attached on the surface of the truck or the head of the equipment with a specified and unique color intensity (after testing this color in the site during variable weather conditions). The color would have to be one that is not similar to other colors on the site so that we can track each truck alone.

5) The location of the web cam should be perpendicular to the entrance and the existence of the project, which would preferably be at the same side as shown in Figure 6.24. It could also be on the top of the site such as in the tower crane head, to have a plan view of the site. This will insure having a good minimum size of pixels for any object during its entrance, existence, and maneuvering inside the construction site.

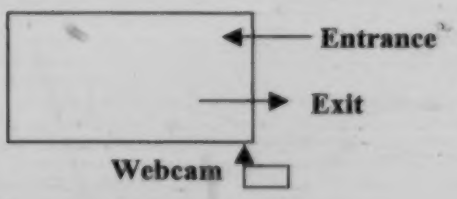



**Figure 6.26 :** Suggested position of the webcam in the construction site

### 6.3.8. SUMMARY

Data acquisition systems in the construction industry involve the use of historical data from a similar completed previous project. This makes the decision support systems relying on this data, which is inaccurate and lack credibility because of the unique environment and variable conditions under which construction projects take place. Using Image processing techniques in these systems will give them more reliability and more precision as a system. It will also help in developing remote management tools, which will improve the efficiency of construction management. This will help in remotely controlling the construction process, which will overcome the problems of construction management in hazardous environments. This paper discussed the principles of image

processing for 2D color images, and proposed a new automated approach using a data acquisition system in construction sites to collect the timecycle of some equipment. Two algorithms for two modules have been developed to analyse images captured by a webcam fixed in the construction site. The advantages of using this methodology over the existing data collection methods, in addition to its limitations in collecting the data of construction sites, have been discussed. Also some recommendations have been defined to apply the 2D color image processing techniques in the construction data collection system. Further work is needed to improve the reliability and flexibility of the system.

### 6.3.9. ACKNOWLEDGMENT

The authors gratefully acknowledge Mr. Amir Eissa at the biomedical department, at the University of Alberta for his technical support and advice during the development of second module using the Matlab programming language.

### 6.3.10. REFERENCES

- Stentz, A., Bares, J., Singh, S., and Rowe, P. (1998). "A robotic excavator for autonomous truck loading." Proceedings IEEE/RSJ International Conference on Intelligent Robotic Systems, October, Victoria, B.C., Canada.
- AbdelRazig, Y. (1999). ''Construction quality assessment: A hybrid decision."
- Abeid, J. N., Arditi, D., and Evens, M. W. (2002). "Using colors to detect structural components in digital pictures." Computer-Aided Civil and Infrastructure Engineering, Vol. 17, pp. 61-67.

- Beliveau, Y. J. (1996). "What can positioning do for construction?" Automation in Construction, Vol. 5, pp. 79-89.
- Chael, M. J., and Abraham, D. M. (2001). "Neuro-Fuzzy approaches for sanitary sewer pipeline condition assessment." Journal of Computing in Civil Engineering, Vol. 15, No. 1, January, ASCE.
- Chen, P., Chan, Y., Chang, L., and Doerschuk, P.C. (2002). "Application of Multi-resolution Pattern Classification to Steel Bridge Coating Assessment." Journal of Computing in Civil Engineering, Vol. 16, No. 4, October, ASCE.
- Cheok, G. S., Stone, W. C., Lipman, R., and Witzgall, C. (2000). "Ladars for construction assessment and update." Automation in Construction, Vol. 9 pp. 463–477.
- Cho, Y., Haas, C. T., Liapi, K., and Sreenivasan, S.V. (2002). "A framework for rapid local area modeling for construction automation." Automation in Construction, Vol. 11, pp. 629– 641.
- Dozzi, S. P., and AbouRizk, S.M. (2003). "Productivity in Construction., a report submitted to Institute for Research in Construction." National Research Council, Ontario, Canada.
- Batllea, J., Casalsb, A., Freixeneta, J. and Martý, J. (2000). "A review on strategies for recognizing natural objects in colour images of outdoor scenes." Image and Vision Computing, Vol. 18, pp. 515–530.
- Karimi, H. A., Khattak, A. J., and Hummer, J. E. (2000). " Evaluation of mobile mapping systems for roadway data collection." Journal of Computing in Civil Engineering, Vol. 14, No. 3, July, ASCE.

- Kim, H., Haas, C. T., Rauch, A. F., and Browne, C. (2002). "Dimensional Ratios for Stone Aggregates from Three-Dimensional Laser Scans." Journal of Computing in Civil Engineering, Vol. 16, No. 3, July 1, ASCE.
- Masad, E., Muhunthan, B., Shashidhar, N., and Harman, T. (1998). "Internal structure characterization of asphalt concrete using image analysis." Journal of Computing in Civil Engineering, Vol. 13, No. 2
- Muhunthan, E. M., Shashidhar, N., and Harman, T. (1999). "Internal structure characterization of asphalt concrete using image analysis." Journal of Computing in Civil Engineering, Vol. 13, No. 2, April, ASCE.
- Ohta, Y., Kanade, T., and Sakai, T. (1980). "Color information for region segmentation." Computer Graphics and Image Processing, Vol. 13, pp. 222–241.
- Pla-Rucki, G. F., and Eberhard, M. (1995). "Imaging of reinforced concrete: state of the art review." Journal of Infrastructure systems, ASCE, Vol 1, No.2
- Rajasekaran, S., and Pai, V. G. A. (2000). "Simplified fuzzy art map as pattern recognizer." Journal of Computing in Civil Engineering, Vol. 14, No. 2, April, ASCE.
- Rens, K. L., Transue, D. J., and Schuller, M. P. (2000). "Acoustic topographic imaging of concrete infrastructure." Journal of Infrastructure Systems, Vol. 6, No. 1, ASCE.
- Russ, J. C. (1995). "The Image Processing Handbook, 2nd Edition." CRC Press.
- Savransky, S. D. (2000). "Engineering of creativity: introduction to TRIZ methodology of inventive problem solving.", Boca Raton, Fla.: CRC Press.

- Shih, N.J (2002). "The Application of a 3D Scanner in the representation of Building Construction Site."
- Sonka, M., Hlavac, V., and Boyle, R. (1999). "Image Processing, Analysis, and Machine Vision." PWS Publishing, second edition.
- Stone, W., and Juberts, M. "2002". "Towards the Ultimate Construction Site Sensor, official contribution of the National Institute of Standards and Technology (NIST). Support model using image processing and neural learning for intelligent defects recognition.'' PhD thesis, Purdue University, West Lafayette, Ind.
- Treash, K., and Amaratunga, K. (2000). "Automatic road detection in greyscale aerial images." Journal of Computing in Civil Engineering, Vol. 14, No. 1, January, ASCE.
- Stone, W., Reed, K., Chang, P., Pfeffer, L., and Jacoff, A. (1999). "NIST research toward construction site integration and automation." Journal of Aerospace Engineering, Vol. 12, No. 2, April, ASCE.
- Wang, K.C. P. (2000). "Designs and implementations of automated systems for pavement surface distress survey." Journal of Infrastructure Systems, Vol. 6, No. 1. ASCE.
- Werner, A. M., and Lange, D. A. (1999). "Quantitative image analysis of masonry mortar microstructure." Journal of Computing in Civil Engineering, Vol. 13, No. 2, April, ASCE.

# APPENDIX 1 – CODE OF REAL TIME DATA ACQUISITION SYSTEM

**Loading & Unloading Time Macro Calculations**

```
Sub Macro3()
' ####################################################
' Last updated Macro on Friday 25 July, 2003 at 4:53 PM
' ####################################################
Dim counter As Integer
Dim countera As Integer
Dim countery As Integer
Dim counterz As Integer
Dim fixal As Integer

counter = 1
For countera = 3 To 13
   For counter = counter To counter + 1000
      If Worksheets("Sheet1").Cells(counter, 1).Value = 1 Then
         Worksheets("Sheet1").Cells(countera, 11).Value =
Worksheets("Sheet1").Cells(counter, 4).Value
         Worksheets("Sheet1").Cells(countera, 12).Value =
Worksheets("Sheet1").Cells(counter, 5).Value
```

```
        Worksheets("Sheet1").Cells(countera, 13).Value =
Worksheets("Sheet1").Cells(counter, 6).Value
        Exit For
      End If
    Next counter

    counter = counter + 24

    For counter = counter To counter + 120
      If Worksheets("Sheet1").Cells(counter, 1).Value = 1 Then
        counterz = counter
        fixal = counterz + 30
        For counterz = counterz To counterz + 29
          MyCount = Abs(counterz - fixal)
            If Worksheets("Sheet1").Cells(counterz, 1).Value = 1 Then
              Worksheets("Sheet1").Cells(MyCount, 19).Value =
Worksheets("Sheet1").Cells(counterz, 1).Value
              Worksheets("Sheet1").Cells(MyCount, 20).Value =
Worksheets("Sheet1").Cells(counterz, 4).Value
              Worksheets("Sheet1").Cells(MyCount, 21).Value =
Worksheets("Sheet1").Cells(counterz, 5).Value
              Worksheets("Sheet1").Cells(MyCount, 22).Value =
Worksheets("Sheet1").Cells(counterz, 6).Value
```

```
        End If
    Next counterz

    For countery = 1 To 30
        If Worksheets("Sheet1").Cells(countery, 19).Value = 1 Then
            Worksheets("Sheet1").Cells(countera, 14).Value =
Worksheets("Sheet1").Cells(countery, 20).Value
            Worksheets("Sheet1").Cells(countera, 15).Value =
Worksheets("Sheet1").Cells(countery, 21).Value
            Worksheets("Sheet1").Cells(countera, 16).Value =
Worksheets("Sheet1").Cells(countery, 22).Value
            For Each c In Worksheets("Sheet1").Range("S1:V30").Cells
              c.Value = ""
            Next
            Exit For
        End If
    Next countery
    counter = counter + 120
    Exit For
End If


' If counter = counter + 120 Then
```

```
    '    Worksheets("Sheet1").Cells(countera, 14).Value =
Worksheets("Sheet1").Cells(counterx - 84, 4).Value
    '    Worksheets("Sheet1").Cells(countera, 15).Value =
Worksheets("Sheet1").Cells(counterx - 84, 5).Value
    '    Worksheets("Sheet1").Cells(countera, 16).Value =
Worksheets("Sheet1").Cells(counterx - 84, 6).Value
    '    Exit For
    ' End If
  Next counter
  If Worksheets("Sheet1").Cells(countera, 14).Value = "" Then
      Worksheets("Sheet1").Cells(countera, 14).Value =
Worksheets("Sheet1").Cells(counter - 84, 4).Value
      Worksheets("Sheet1").Cells(countera, 15).Value =
Worksheets("Sheet1").Cells(counter - 84, 5).Value
      Worksheets("Sheet1").Cells(countera, 16).Value =
Worksheets("Sheet1").Cells(counter - 84, 6).Value
  End If
Next countera
Range("Q3").Select
  Range("Q3:R22").Select
  Selection.NumberFormat = "0.00"
  ActiveCell.FormulaR1C1 = _
    "=(((RC[-1]+60)-RC[-4])+((RC[-2]-1-RC[-5])*60)+((RC[-3]-RC[-6])*60*60))/60"
```

```
    Range("R3").Select
    ActiveCell.FormulaR1C1 = _
        "=(((R[1]C[-5]+60)-RC[-2])+((R[1]C[-6]-1-RC[-3])*60)+((R[1]C[-7]-RC[-
4])*60*60))/60"
    Range("Q3:R3").Select
    Selection.AutoFill Destination:=Range("Q3:R22"), Type:=xlFillDefault
    Range("Q3:R22").Select
End Sub
```

**First & Second Module for Real Time Data Acquisition System**

```
%*************************************************************************
*** This file is designed to read a series of jpg images for construction
%project every 10 seconds to recognize the object of dumping trucks in the
%site, and its loading time during the excavation process
%*************************************************************************
clear all;



%
*************************************************************************
%*** This Module is developed to recognize colors of main Trucks or Objects
%****************** in any construction site ****************************
%*************************************************************************
**
button = questdlg('Choose Image File for Each Truck before You Start Data Acquistion
System',...
'Truck Color Recognition Module','Yes','No','Help','Yes');
if strcmp(button,'Help')
   disp('Sorry, no help available')
elseif strcmp(button,'No')
   disp('Sorry, you choosed to terminate the module')
```

```
elseif strcmp(button,'Yes')
   [FileName,PathName] = uigetfile('*.jpg','Select the Image-file');

- %for m=1:50
 button = questdlg('Do you want to continue with this image?',...
'Continue Operation','Yes','No','Yes');
 if strcmp(button,'Yes')
 f1=PathName;
 f2=FileName;
 filename=strcat(f1,f2);
 h=imread(filename);
 Figure(1)
 image(h)

 [Y,X]= ginput (1);
 X=round(X);
 Y=round(Y);            % Mark the area of interest and define the X and Y coordinates
                        % of the four corners

 length=5;              % Define the length of the Moving Square Block
```

```
%threshold=100;          % Define a threshold value, below which, any pixel value will
be neglected


xmin=X-3;                % Redefine the minimum border for X and Y to make the full
length of
xmax=X+3;                % Area of Interest, equal to a multiple of the SQUARE
Block's Length
ymin=Y-3;
ymax=Y+3;



%xmin=uint(16);
%xmax=uint(16);
%ymax=uint(16);
%ymin=uint(16);


k=h(xmin:xmax,ymin:ymax,:);


Figure(2)
image(k)
```

```
%ID=1;
k=double(k);

elseif strcmp(button,'No')

end
for i=1:7;
  for j=1:7
    h1(i,j)=k(i,j,1);
    h2(i,j)=k(i,j,2);
    h3(i,j)=k(i,j,3);
    K(i,j)=(h1(i,j)+h2(i,j)+h3(i,j))/3;
    Q=median(median(K(i,j)));
  end
end
%Recog_Matrix(1,1)=ID;
%Recog_Matrix(1,2)=K1;
%Recog_Matrix(1,3)=Description;

%%%
```

```
% directory of work for Matlab
%%%
```

```
   disp('Sorry, no help available')
elseif strcmp(button,'No')
   disp('Sorry, you choosed to terminate the module')

elseif strcmp(button,'Yes')
   [FileName,PathName] = uigetfile('*.jpg','Select the Image-file');

%for m=1:50
 button = questdlg('Do you want to continue with this image?',...
'Continue Operation','Yes','No','Yes');
if strcmp(button,'Yes')
f1=PathName;
f2=FileName;
filename='image_030321_070002.jpg';
%filename='image_030331_071312.jpg';      % Enter File Name here
%filename=strcat(f1,f2);
%h=imread(filename);
%Figure(1)
%image(h)
                    % Enter path here (instead of TEST)
```

```
a=double(filename(8))-48;
b=double(filename(7))-48;
year=a+10*b;
a=double(filename(10))-48;
b=double(filename(9))-48;
month=a+10*b;
a=double(filename(12))-48;
b=double(filename(11))-48;
day=a+10*b;

a=double(filename(15))-48;
b=double(filename(14))-48;
hour=a+10*b;


a=double(filename(17))-48;
b=double(filename(16))-48;
minute=a+10*b;


a=double(filename(19))-48;
b=double(filename(18))-48;
second=a+10*b;
```

```
% open first file here
A=imread(filename,'JPEG');
Figure(3)
image(A)
title('Click the four corners of The Region of Interest, start by upper left Corner and go
clockwise')
%       Define the area of the image which we will process (where
%       the trucks of interest (come in), (stay for work), AND (go out)

    [X2,X]= ginput (4);
    X=round(X);
    X2=round(X2);          % Mark the area of
                           % interest and define the X and
                           % Y coordinates of the four
                           % corners

length=15;                 % Define the length of the Moving Square Block

threshold=50;              % Define a threshold value, below which, any pixel
value will be neglected
```

```
xmin=min(X);                % Redefine the minimum border for X and Y to make the
full length of
xmax=max(X);                % Area of Interest, equal to a multiple of the SQUARE
Block's Length
ymin=min(X2);
ymax=max(X2);

gg=xmax-(xmin-1);
gg1=gg/length;
gg2=floor(gg1);

residue=gg1-gg2;
residue=residue*length;

xmin=xmin+residue;

xblocks=gg2;                % xblocks and yblocks will hold the number of square we
will have to check along each axis

gg=ymax-(ymin-1);
gg1=gg/length;
gg2=floor(gg1);
```

```
residue=gg1-gg2;
residue=residue*length;
ymin=ymin+residue;
yblocks=gg2;
clear gg2;
clear gg;
clear gg1;

XMIN=xmin;
YMIN=ymin;
XMAX=xmax;
YMAX=ymax;

xmin=uint(16);
xmax=uint(16);
ymax=uint(16);
ymin=uint(16);

xmin=XMIN;
ymin=YMIN;
xmax=XMAX;
ymax=YMAX;
```

```
A=A(xmin:xmax,ymin:ymax,:);
Figure(4)
image(A)
A=double(A);
kk=1;
for k=1:1308
 % for k=1:3830    the original one
% Define Next File Name
        % Increment the Time Stamp

          .% In this Section we're trying to logically detect reddish car's color
          % and find its position using this color detection

H1=A+5;              % Add 5 to original image values to avoid later dividing by zero

%********************************* New Approach*********************
Rang=3;

H(:,:,1)=H1(:,:,1)./H1(:,:,2);        % get the average of colors 1 and 2
H(:,:,2)=H1(:,:,2)./H1(:,:,3);        % get the average of colors 2 and 3
H(:,:,3)=H1(:,:,1)./H1(:,:,3);        % get the average of colors 1 and 3
```

```
L11(:,:,1)=H(:,:,1)<(Cmean1*(100+Rang)/100);
L12(:,:,1)=H(:,:,1)>(Cmean1*(100-Rang)/100);
L21(:,:,1)=H(:,:,2)<(Cmean2*(100+Rang)/100);
L22(:,:,1)=H(:,:,2)>(Cmean2*(100-Rang)/100);
L31(:,:,1)=H(:,:,3)<(Cmean3*(100+Rang)/100);
L32(:,:,1)=H(:,:,3)>(Cmean3*(100-Rang)/100);
Level=((H1(:,:,1) + H1(:,:,2)+H1(:,:,3))/3)>Q;
L1=L11(:,:,1)&L12(:,:,1);
L2=L21(:,:,1)&L22(:,:,1);
L3=L31(:,:,1)&L32(:,:,1);
L4=L1&L2;
L5=L3&Level;
L6=L4&L5;
%**********************************End of new Approach***************

%%%%%%%%%%%%%%%%%%%%  Old Approach %%%%%%%%%%%%
%H(:,:,2)=(H1(:,:,2)+H1(:,:,3))/2;          % get the average of colors 2 and 3
%H(:,:,3)=H1(:,:,1)./H1(:,:,2);             % Divide color 1 (Red Component) by the above
%H(:,:,1)=H1(:,:,2)./H1(:,:,3);             % Divide color 2 by color 3 to check on
                                            % their being close in values
```

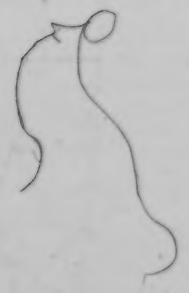
```
%L1=H(:,:,3)>1.5;          % Those three lines are to make sure the color is appropriate
RED
%L2=H(:,:,3)<2;          % (The red component is higher than others)
%LL=L1 & L2;


%L3=H(:,:,1)>80;                % Here we're making sure that the Red component is
big/bright
%L4=LL & L3;                % enough to be used in our logic
%L1=H(:,:,1)<1.2;          % Those three lines are to make sure the color is appropriate
RED
%L2=H(:,:,1)>0.8;          % (The red component is higher than others)
%LL=L1 & L2;
%L3=LL & L4;
%[I,J]=find(LL);
%************************* End of this Old approach *********************
[I,J]=find(L6);
truckX=median(I);
truckY=median(J);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
B=imread(filename,'JPEG');                % Open Next File
B=B(xmin:xmax,ymin:ymax,:);
A=double(B);
```

```
% Now that we have some locations where the maximum color value exists, we
% need to select only one of these possible locations to be the object's
% location, and this will be done using median function
TruckX=floor(truckX);
TruckY=floor(truckY);
TruckX=TruckX+xmin-1;
TruckY=TruckY+ymin-1;
% Decision making about Truck that did not move or moved outside the view
% (no TruckX or TruckY is found), We need to put the logic here for this
% situation where the subtraction result is almost ZERO or the positive
% value in subtraction is giving a false object (like a sunny spot that
% gets uncovered by a truck's leaving this area)
% Put all the variables of interest in one Matrix together
TruckID=1;
% just a random value untill we decide how to give ID's to the trucks
if size(I)<50
   TruckX=0;
   TruckY=0;
   TruckID=0;
end
% in the next few lines, kk is the X-index for Time_Matrix, and we need to
% put some logic that would control a loop that contains the next few lines
% for a certain number of times that should equal the number of chosen
```

```
% (assured real objects) and in this loop, kk has to be incremented so that
% we can add several lines in the Time_Matrix for the same "k" instance. In
% such case we need to address the issue of "TruckID" in more details
Time_Matrix(kk,1)=TruckID;
Time_Matrix(kk,2)=TruckX;
Time_Matrix(kk,3)=TruckY;
Time_Matrix(kk,4)=hour;
Time_Matrix(kk,5)=minute;
Time_Matrix(kk,6)=second;
Time_Matrix(kk,7)=year;
Time_Matrix(kk,8)=month;
Time_Matrix(kk,9)=day;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Save the result to an excel sheet file called " output.xls" at the same %%%%%%
% directory of work for Matlab %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
save('test2.xls', 'Time_Matrix', '-ascii')
kk=kk+1
second=second+30;
if second>59
   minute=minute+1;
   second=second-60;
end
```

```
if minute>59
   hour=hour+1;
   minute=0
end
        % Make the File Name
S1='image_';
Y=year;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
S2=char(Y1);
S3=char(Y);              % Make the year part of the name
Y=month;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
S4=char(Y1);
S5=char(Y);              % Make the month part of the name
```

```
Y=day;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
S6=char(Y1);
S7=char(Y);              % Day part of the name
S8='_';
Y=hour;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
S9=char(Y1);
S10=char(Y);             % Hour part
Y=minute;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
```



```
S11=char(Y1);
S12=char(Y);                % Minute part
Y=second;
Y1=Y/10;
Y1=floor(Y1);
Y=Y-10*Y1;
Y1=Y1+48;
Y=Y+48;
S13=char(Y1);
S14=char(Y);                % Second part
S15='.jpg';                 % Make part for the Extension
filename=strcat(S1,S2,S3,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13,S14,S15);        %
Concatinate (assemble) all parts together
                                                    % to formulate the filename
end
end
%%%
```

# CHAPTER 7. FINAL DISCUSSION

## 7.1. RESEARCH SUMMARY

The integrated simulation system presented in this thesis proposes multi-dimensional solutions. The overall approach of the solution is to develop an automated distributed simulation system based on an information model. Four secondary goals are achieved in accomplishing the primary objective:

1) To conceptualize a new information model and ontology that can be used mainly to develop a distributed simulation system for construction management. Chapters 2 and 3 compared the state-of-the-art in simulation and information models developed in construction research. Then design a new distributed information model that can be used for different end-users within construction management simulation and propose a certain pattern of relationships between its elements.
2) To develop a new distributed integrated simulation system based on an information model and a related ontology approach. Chapter 4 introduces this system and a prototype model for it.
3) To introduce a new automated approach that can be applied in a simulation system. Chapter 5 described a new method of applying natural chemical theories and principles for controlling the information flow in simulation systems. This approach defines new pattern for simulation systems as well as an automated structure for the simulation elements.

4) To survey and analyse Information Technology applications in Construction (ITC). Chapter 6.2 described ITC in research in the last ten years, and defined areas to be investigated in ITC. As well, to develop a new automated data acquisition system. Chapter 6.3 detailed a new methodology to collect data in construction sites using image processing. The approach can be used effectively in hazardous and remote construction sites to collect excavation data.

The presented IICSS simplifies simulation model building without the need for extensive knowledge of simulation for end-users. Furthermore, the simulation elements, their structure, their relationships, and their interactions can be easily integrated with new elements that can be defined in the future, due to new technology applications in the construction industry.

## 7.2. SUMMARY OF RESEARCH CONTRIBUTIONS

The research outlined in this thesis is a trial to develop an integrated simulation system for construction management. The research has resulted in the following major contributions:

1) Integration of information and simulation modeling

The framework proposed in the thesis contributes in a number of ways to construction management research. It simplifies the building of a simulation model by providing common generic determined elements and their relationships under a distributed simulation environment. It enables various end-users of the industry to benefit, at the same time, from the developed simulation model. It

integrates several construction management processes under the same simulation umbrella.

2) New distributed information-based integrated simulation system

The developed conceptual information model translated into an integrated simulation system using a distributed simulation system called HLA. A prototype model was developed to approve this approach. The system will enable users of simulation to illustrate the capabilities of distributed simulation as well as the control of data flow between the simulation elements in a systematic generic pattern.

3) New automated anatomy for simulation elements

The research introduces, for the first time, the application of interaction, structure theories, and principles in nature to be applied in building a simulation system. It simulates a chemical environment to create a new automated simulation system. It is expected that the introduction of chemistry to the construction management simulation community will greatly affect the way that simulation systems are designed and built. It will also trigger a number of successive research tracks that benefit from chemical theories and principles in ways beyond what is described in this thesis.

4) Analysis of ITC research and new approach for automated data acquisition system

The research investigated trends of ITC research in the last ten years and defined recommendations for new research areas of ITC that can be utilized in the future. The approach described in this thesis represents a unique automated approach for

data acquisition system using image processing that can be applied in hazardous and/or remote construction sites for collecting excavation data.

## 7.3. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

The presented research exposes other research areas that need further development and study. Recommendations for further study are as follows:

1) Implement the entire construction management process, including, but not limited to, quality control, document control, and change management. This will make IICSS more valuable.
2) Implement IICSS on more complex projects to investigate the efficiency of the new proposed system.
3) Develop a graphical user interface for a simulation elements periodic table that eases the way of developing a model for end-users as well as simplifies the way of adding new elements to the table.
4) Study other simulation elements structures in construction management processes and their interactions equations patterns. This will increase the reliability of the system. On example is state changes of construction elements.
5) Investigate new methods to change ownership services in the HLA environment during a simulation run.
6) Explore other theories and principles in chemistry that can be simulated in developing IICSS. It is expected that a more standard simulation pattern could be developed.

7) Investigate a new data acquisition system under severe weather conditions and develop this system as an element inside the IICSS structure.

8) Explore the possibilities of linking the actual status of these elements for an under-progress project to the IICSS elements during a simulation run.

9) Investigate the design of elements that represent applications tools, such as the Fuzzy Set and Neural Network, and how to integrate them with the IICSS structure and its elements.

10) Analyse other attributes that can be added to the management object model. The research outlined here was limited with time, space, and a huge amount of objects and their attributes that can be integrated within IICSS. More research in this direction can increase the reliability of the system to be applied in the industry.